Comparison of water vapor from AIRS and VCSEL hygrometer during START08/HIPPO Global

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NSF HAIS, ATM-084732, NASA

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Greenbelt, Maryland

Outline

I. NSF VCSEL hygrometer

II. Intercomparisons

III. START08 / HIPPO field campaigns

IV. Comparison with AIRS

V. Ice supersaturations

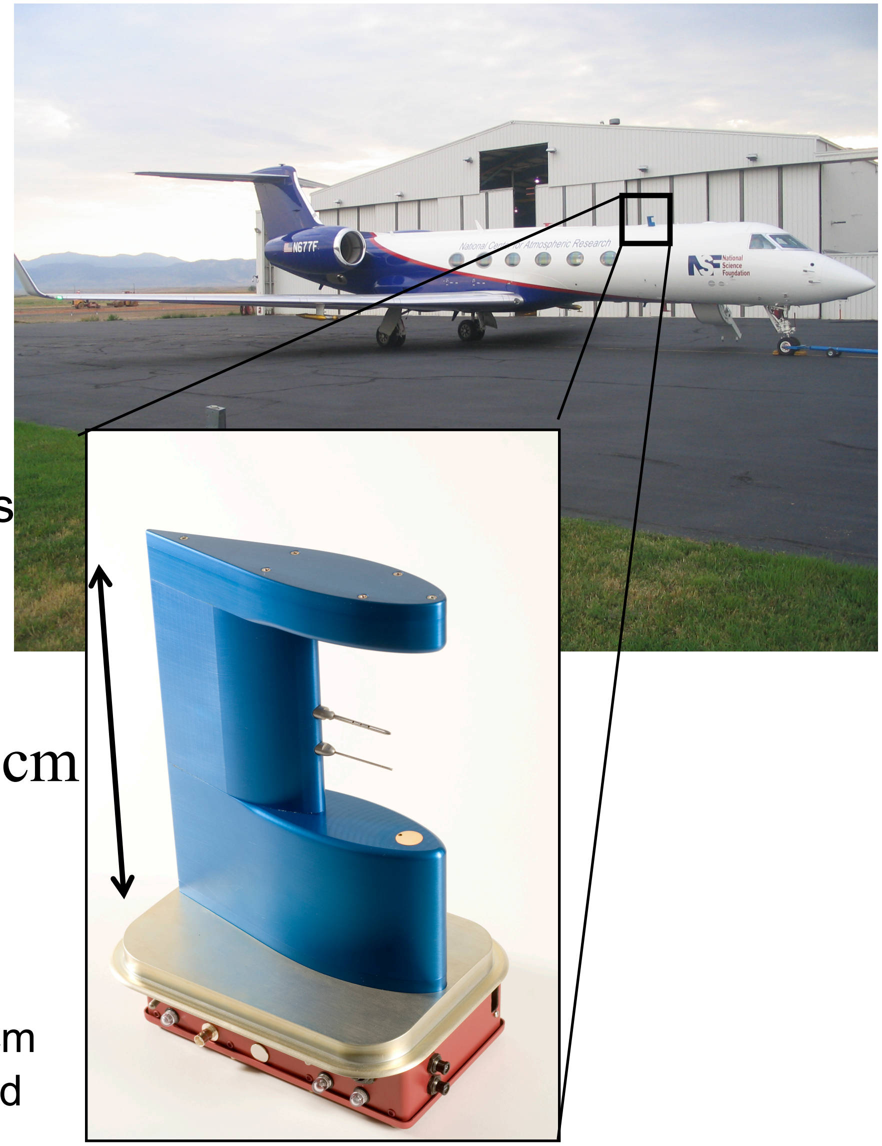
V. Conclusions

Goals: quantify AIRS and VCSEL agreement over Pacific and land areas

Science questions:

How well can AIRS H_2O data be used for land surface hydrology?
What is the climatology of ice supersaturated areas in the UT?

NSF Gulfstream-V VCSEL sensor



NSF Gulfstream-V research aircraft: new opportunities for atmospheric research
duration: 15 hrs., speed: Mach 0.8
horizontal range: 1/4 Earth
vertical range: 0.1-15 km

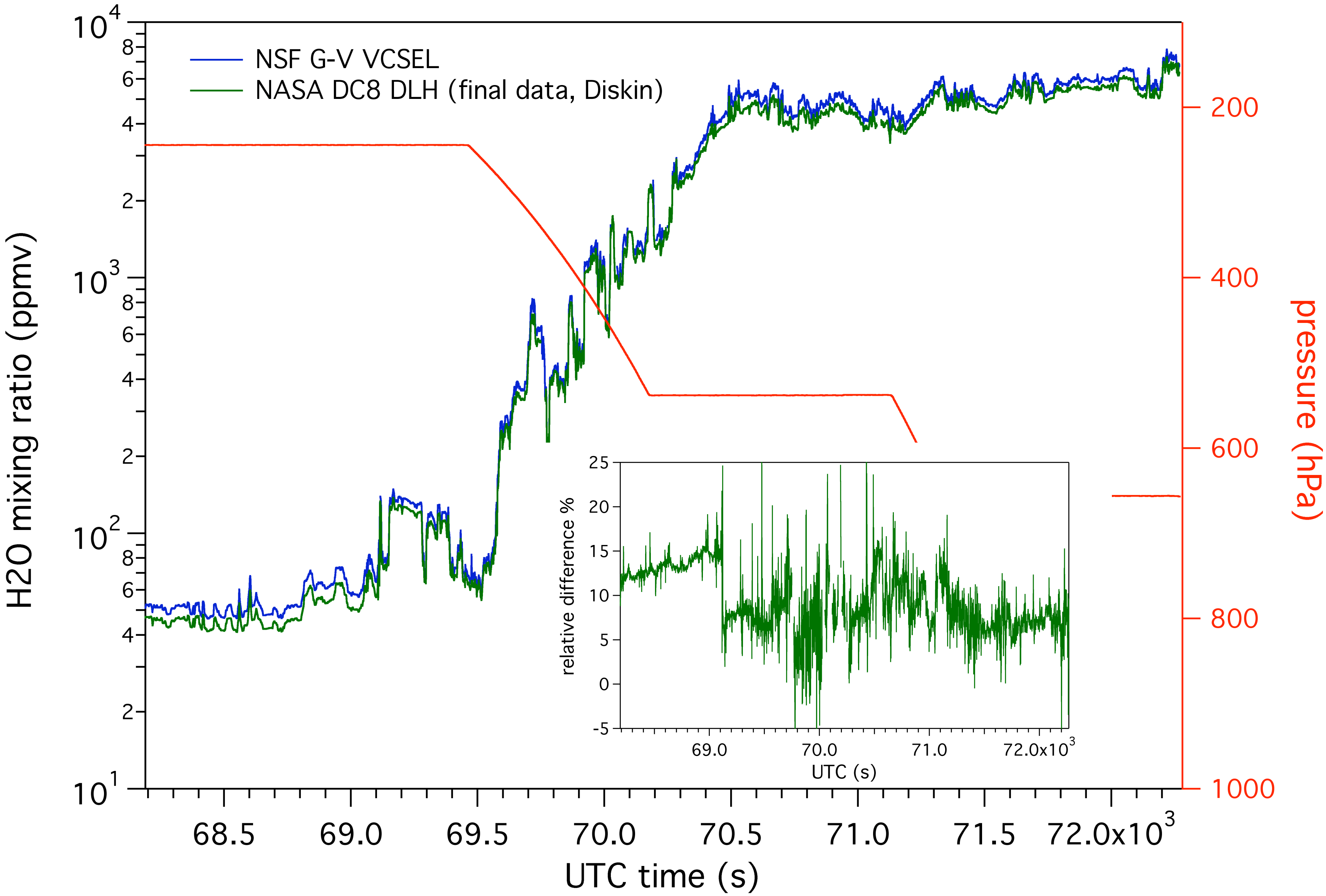
1854 nm fiberized VCSEL controlled by DSPs

29 cm

Parameter	Specifications
Dew point range	-110°C to +30°C
Sensitivity (SNR=1, 1 Hz)	0.05 ppmv
Frequency	25 Hz
Accuracy	≤ 5%
Precision	≤ 3%
Power	5 W
Weight	5 kg
Size	25 cm × 16 cm × 5 cm
Operation	unattended

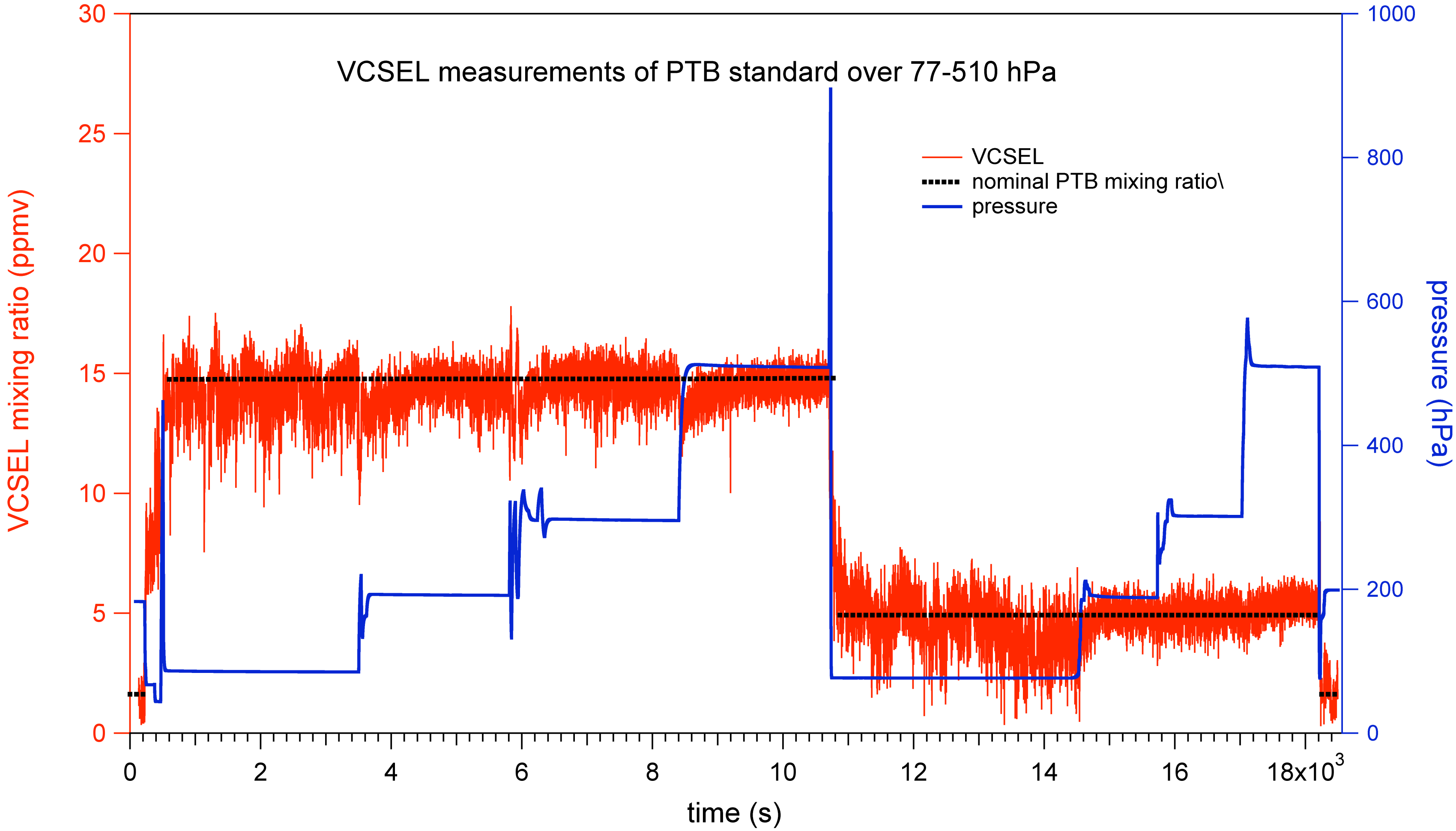
VCSEL hygrometer designed for G-V ranges of tropical, boundary layer to the lower stratosphere

RF 17: G-V VCSEL and DC-8 DLH intercomparison



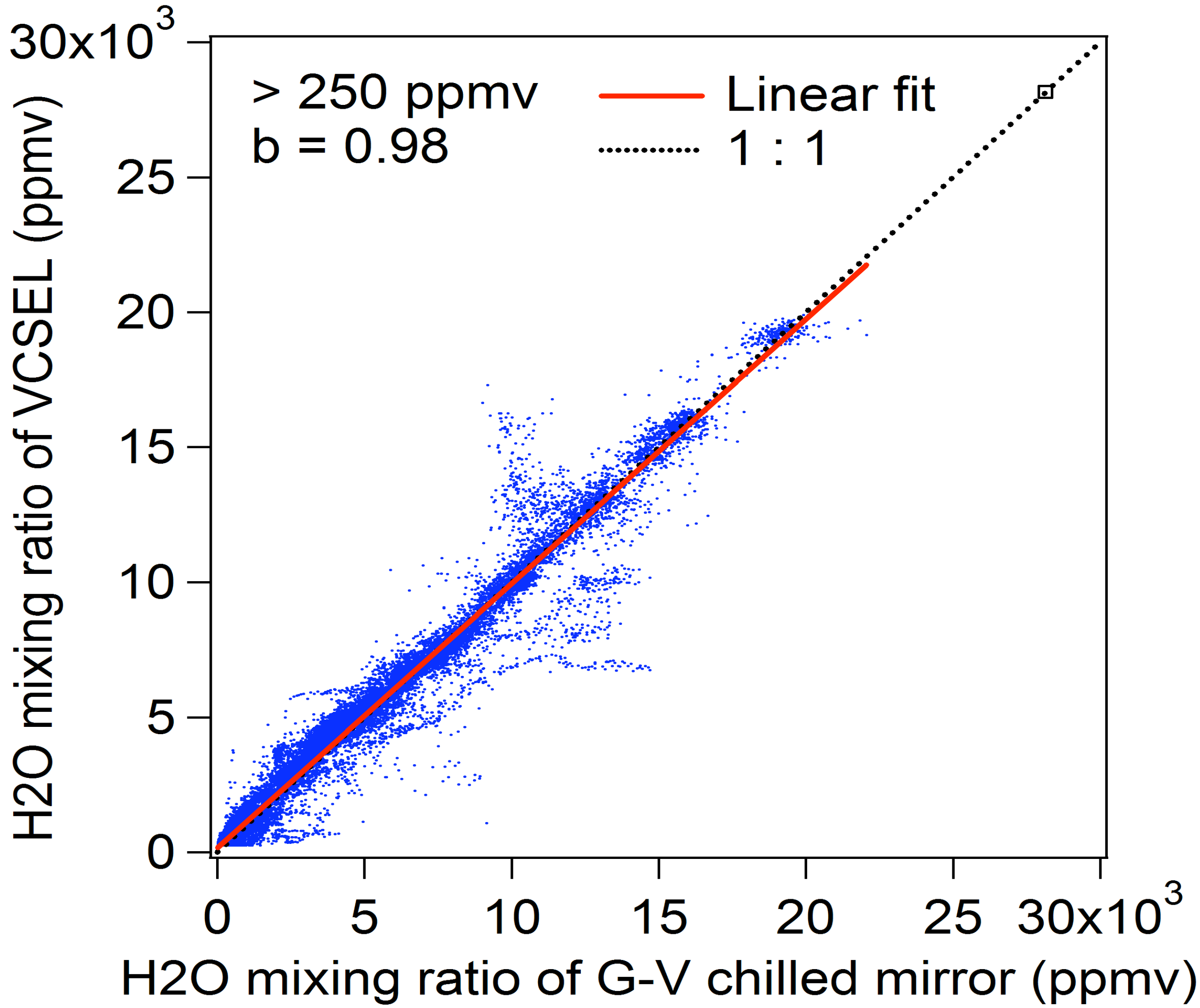
~ 8% higher than DLH on average

AquaVIT blind intercomparison (AIDA chamber)



Calibration methods agree with AquaVIT intercomparison standard over 4.79 to 14.5 ppmv over range of pressures

Comparison to G-V chilled mirror

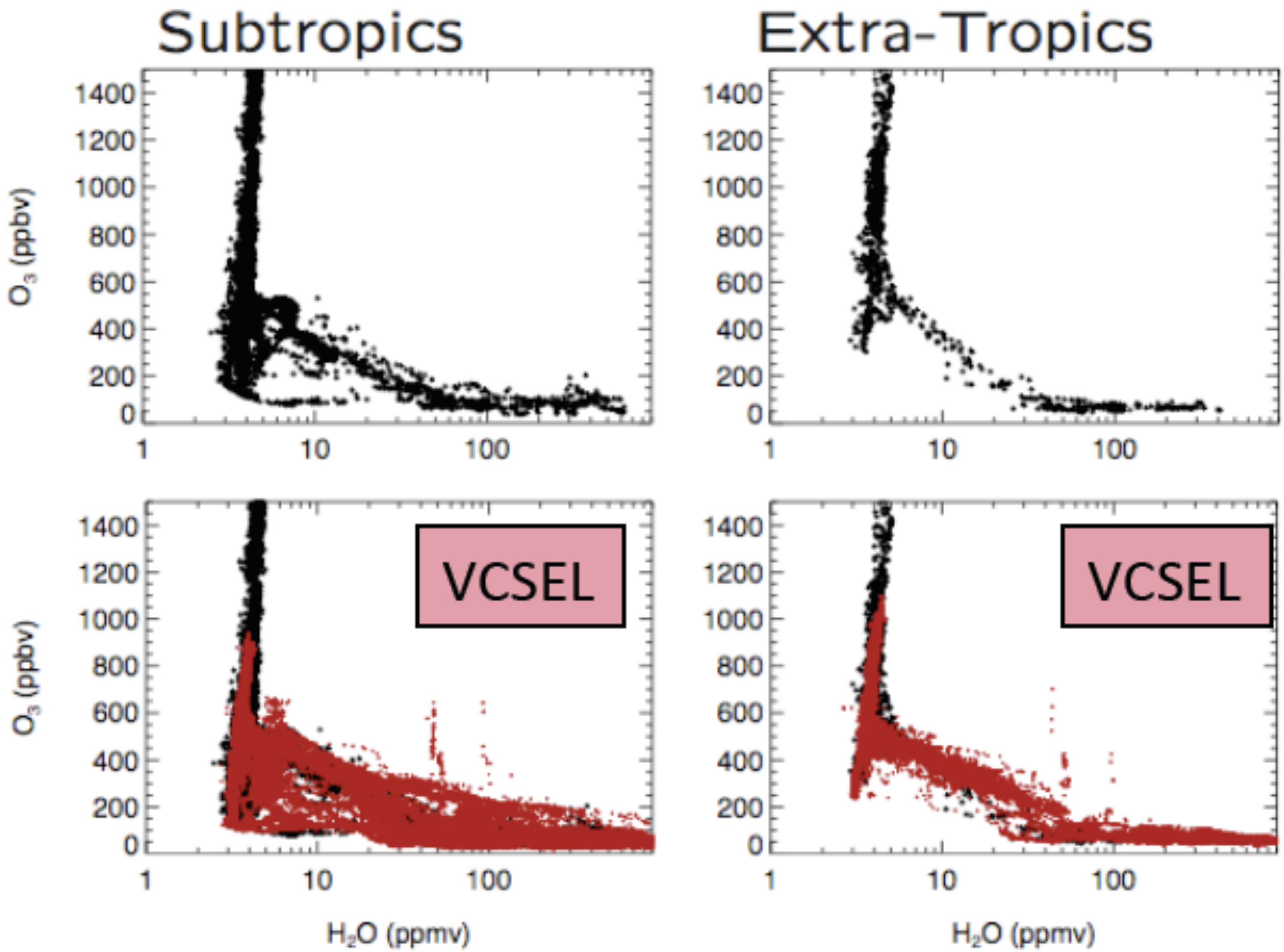


2% agreement between sensors up to 20,000 ppmv

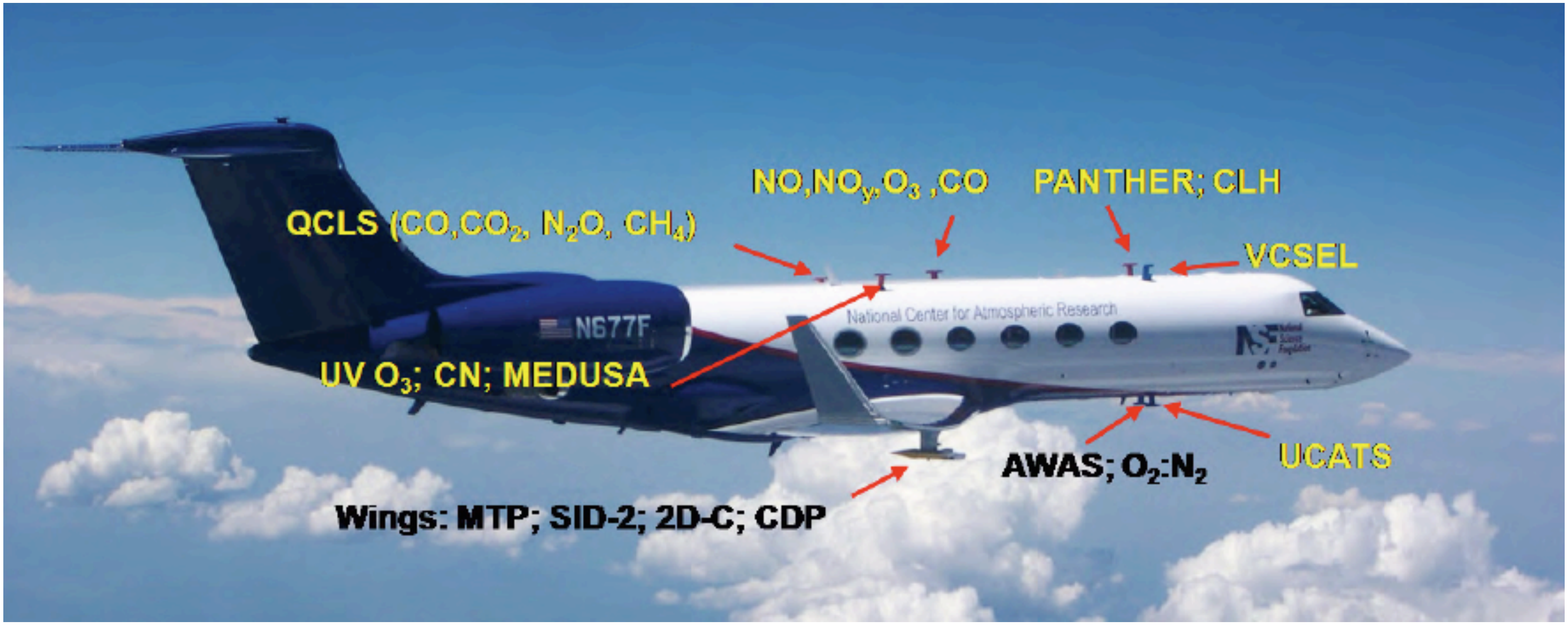
Tracer-tracer correlations: O_3 vs. H_2O (spring)

STRAT
POLARIS

START08

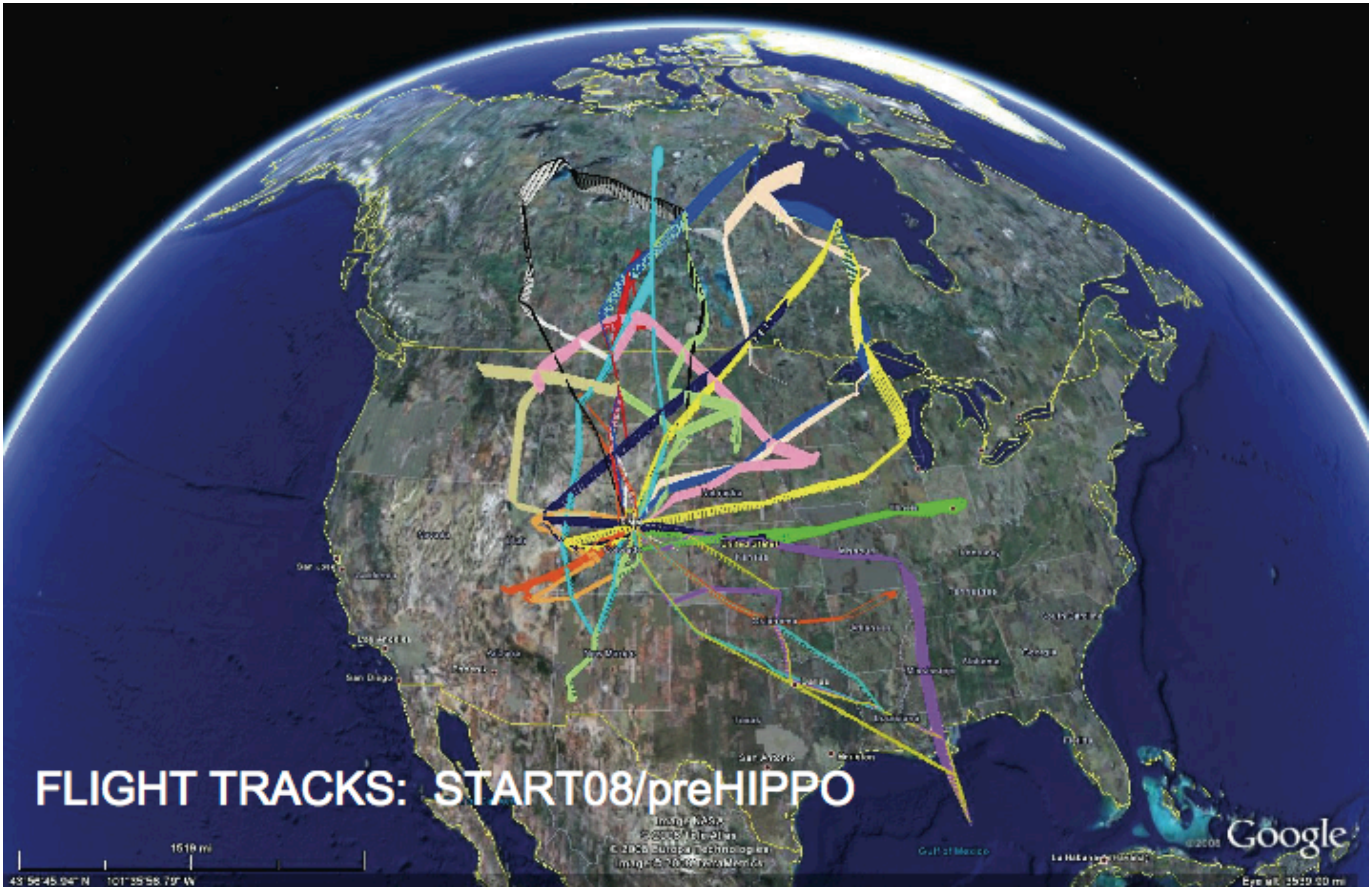


Stratosphere-Troposphere Analyses of Regional Transport (START08) field experiment



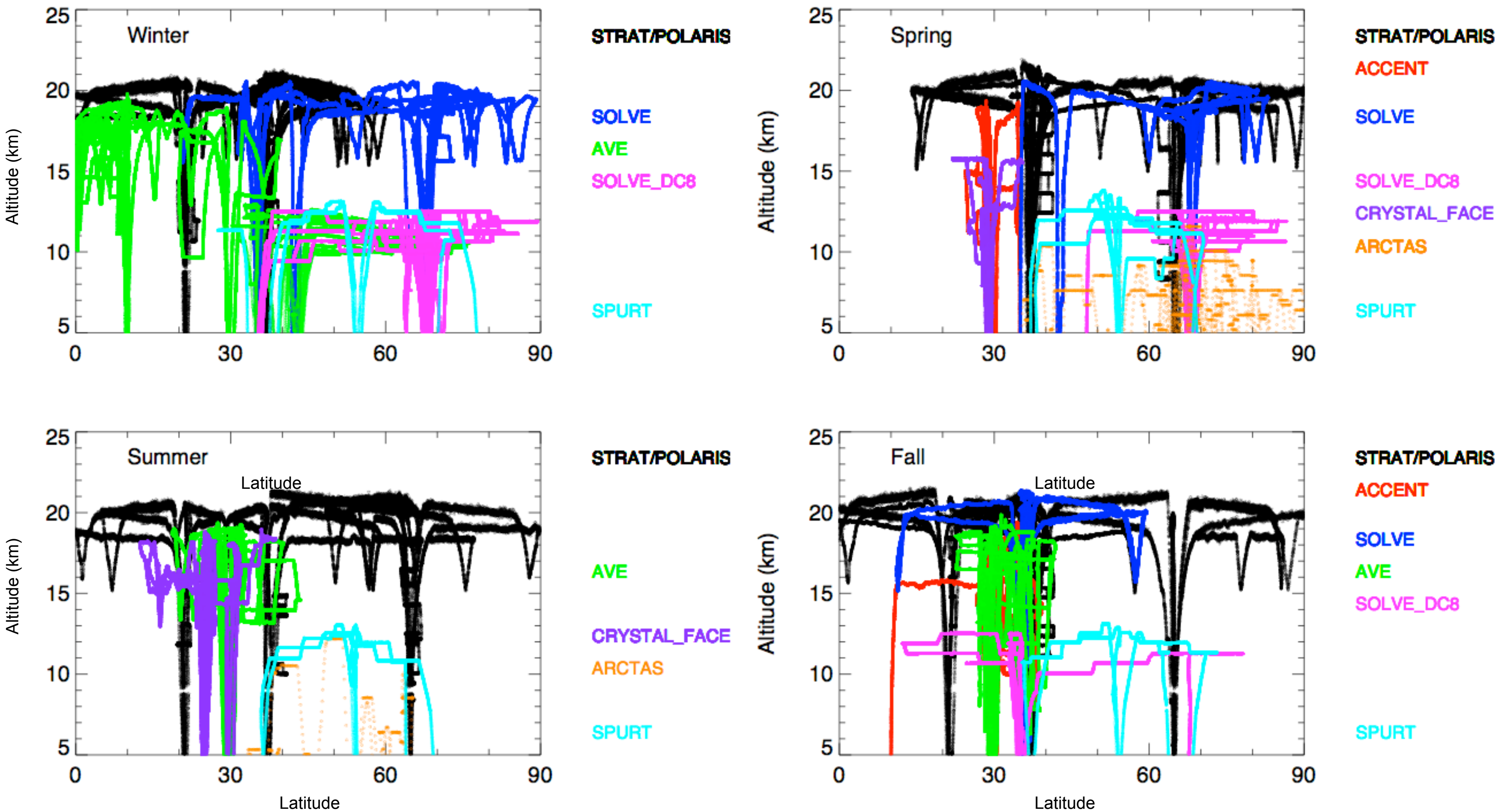
Field campaign based out of Colorado (April-June 2008)
Examining how air from stratosphere/troposphere exchanges around mid-latitude storms and jet streams
Tropopause boundary usually involves dips, discontinuities
Synthesis of aircraft measurements, model, and satellite data

START08/PreHIPPO flight tracks

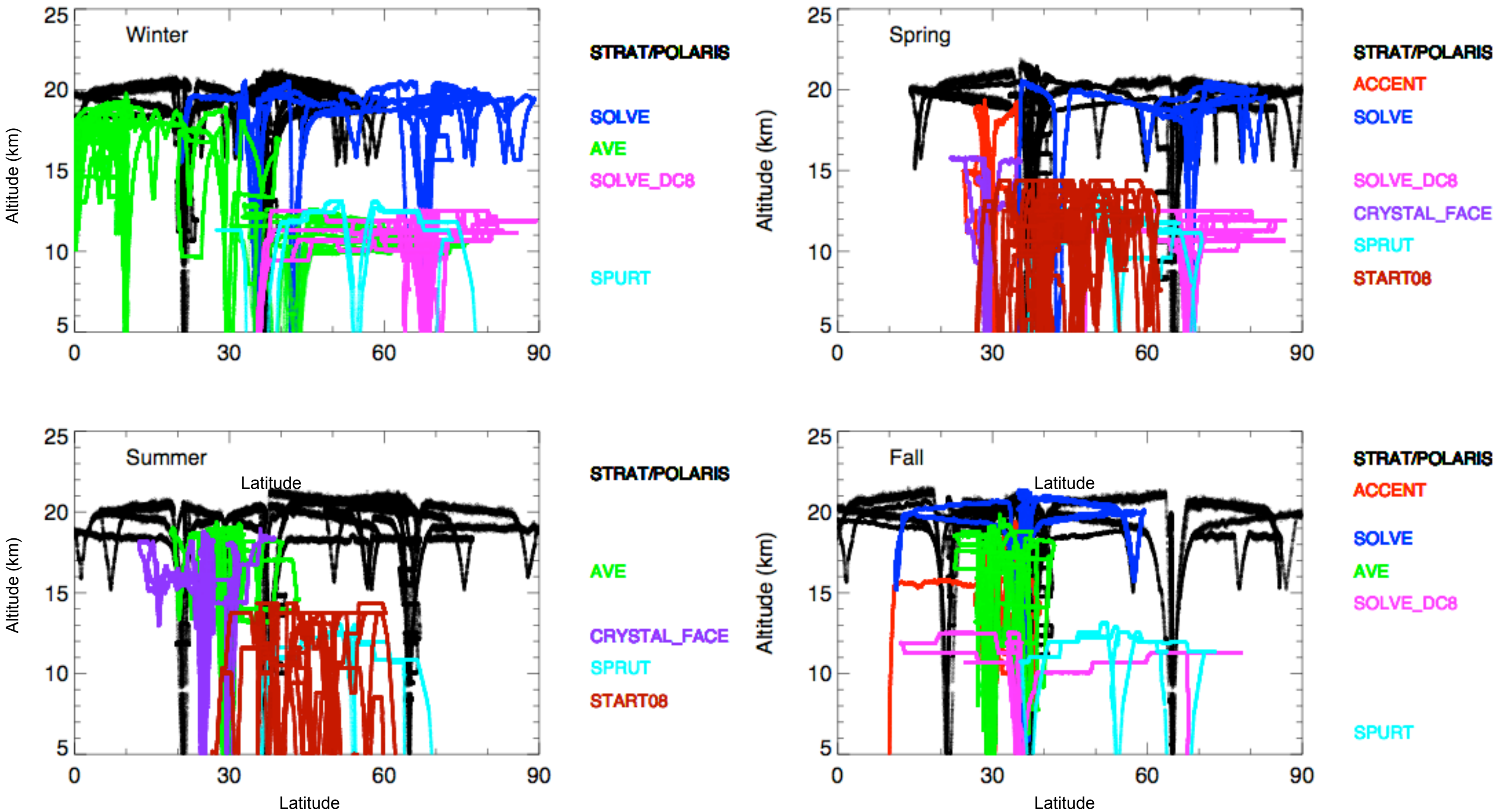


Mid-latitude coverage from Tropic of Cancer to Arctic Circle

Coverage of UTLS in Aircraft Campaigns (before START08)

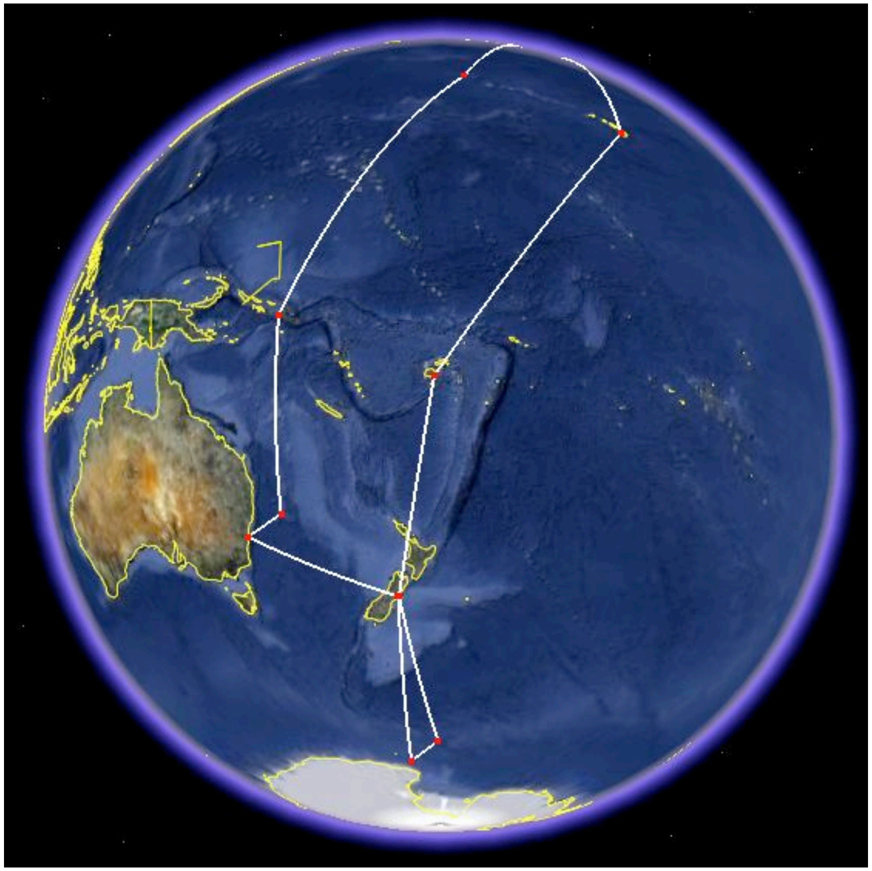


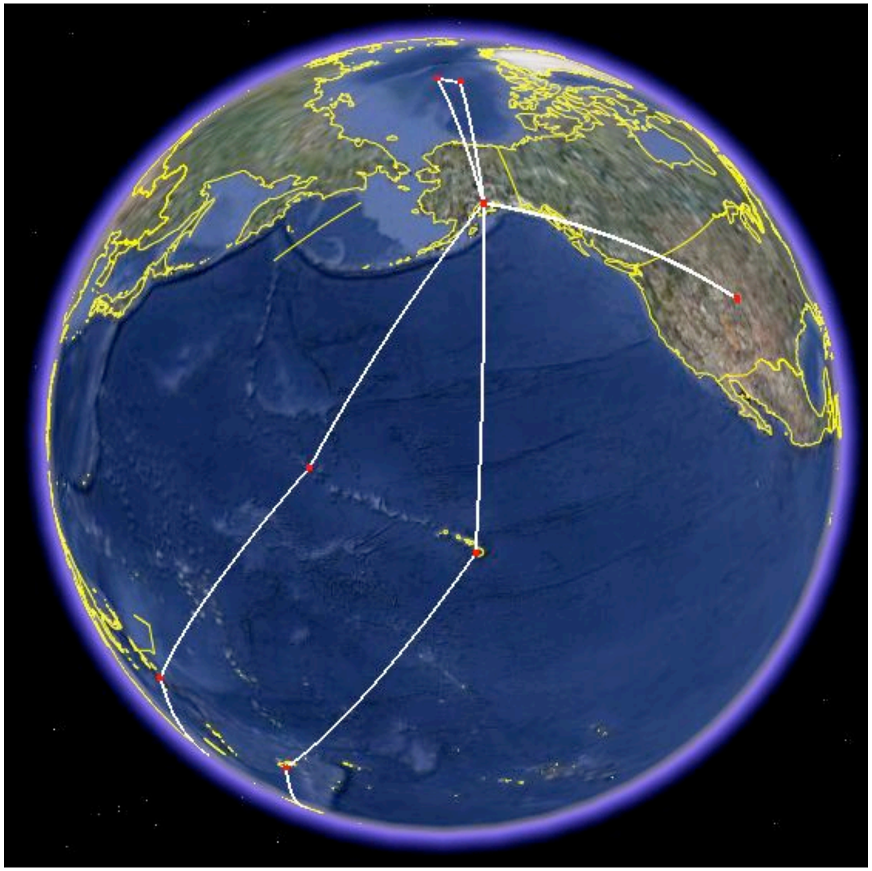
Coverage of UTLS in Aircraft Campaigns (with START08)



HIAPER Pole-to-Pole Observations of Greenhouse Gases and the Carbon Cycle

Deployment #1: 09-30 January 2009
46 000 km
135 Vertical Profiles

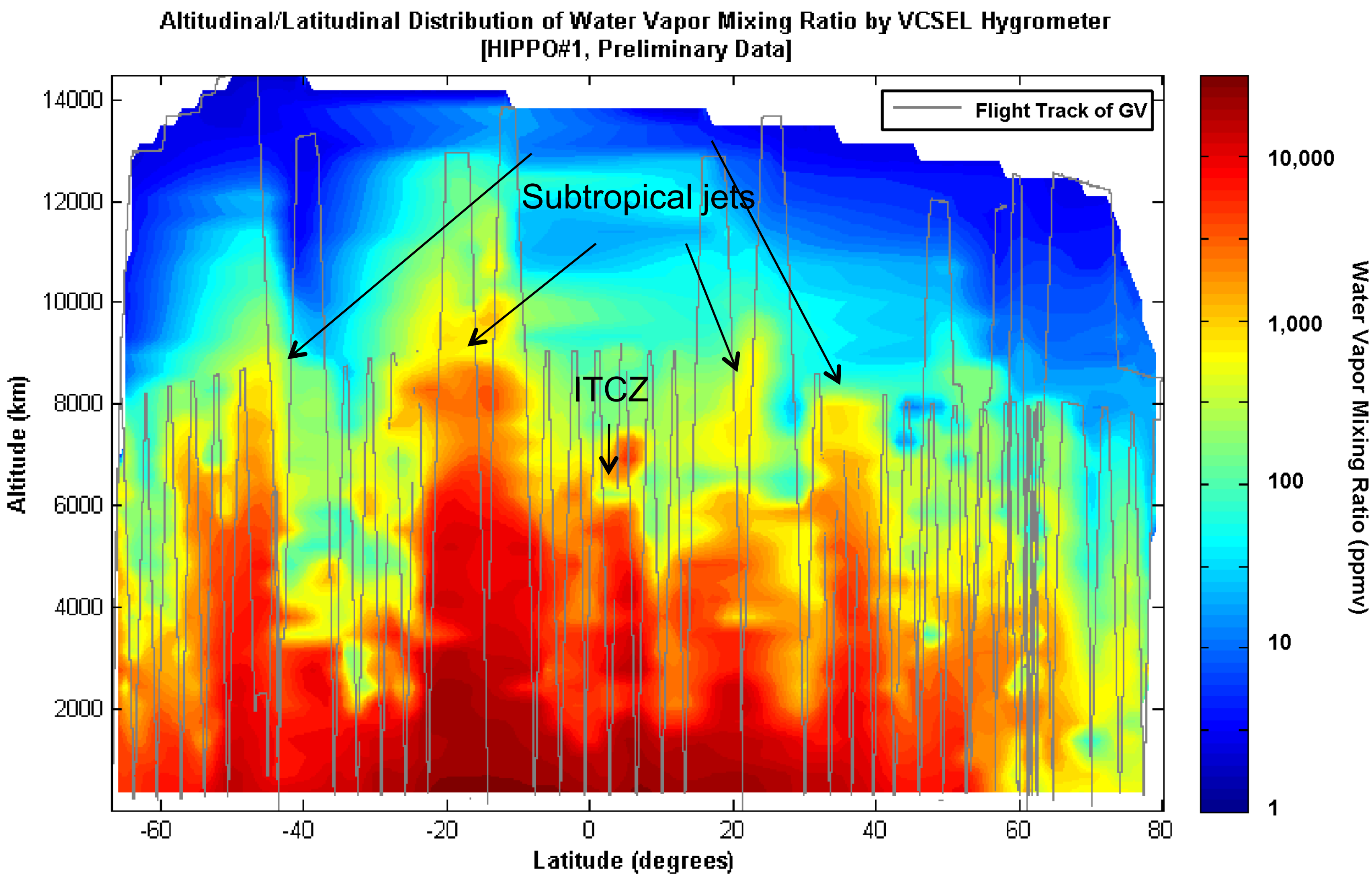




Additional global missions:

Fall: Oct. 25-Nov. 17, 2009
Spring: April 2010
Summer: June 2011; Aug. 2011

Water vapor meridional/vertical distribution



M. Zondlo and M. Diao

Global in nature and extremely fine grained

Analyses for AIRS / VCSEL intercomparisons

AIRS data: Level 2 standard product, v5

VCSEL: 5 s data; final data START08, preliminary data HIPPO Global #1

Criteria:

Distance: coincident, 22.5, 50, 100 ... 600 km

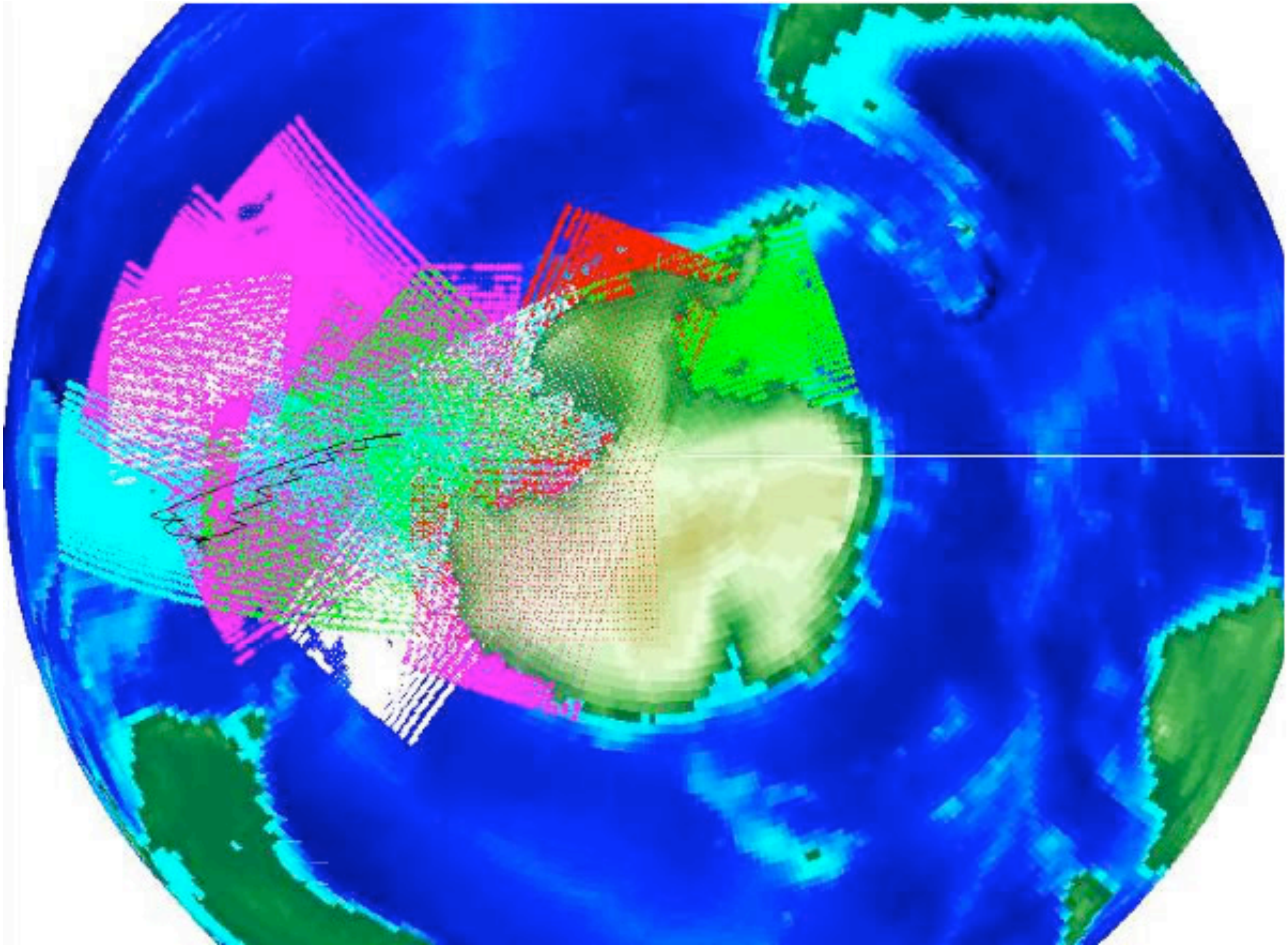
Time: coincident, 90, 120, 180 …1440 min

Constant pressure

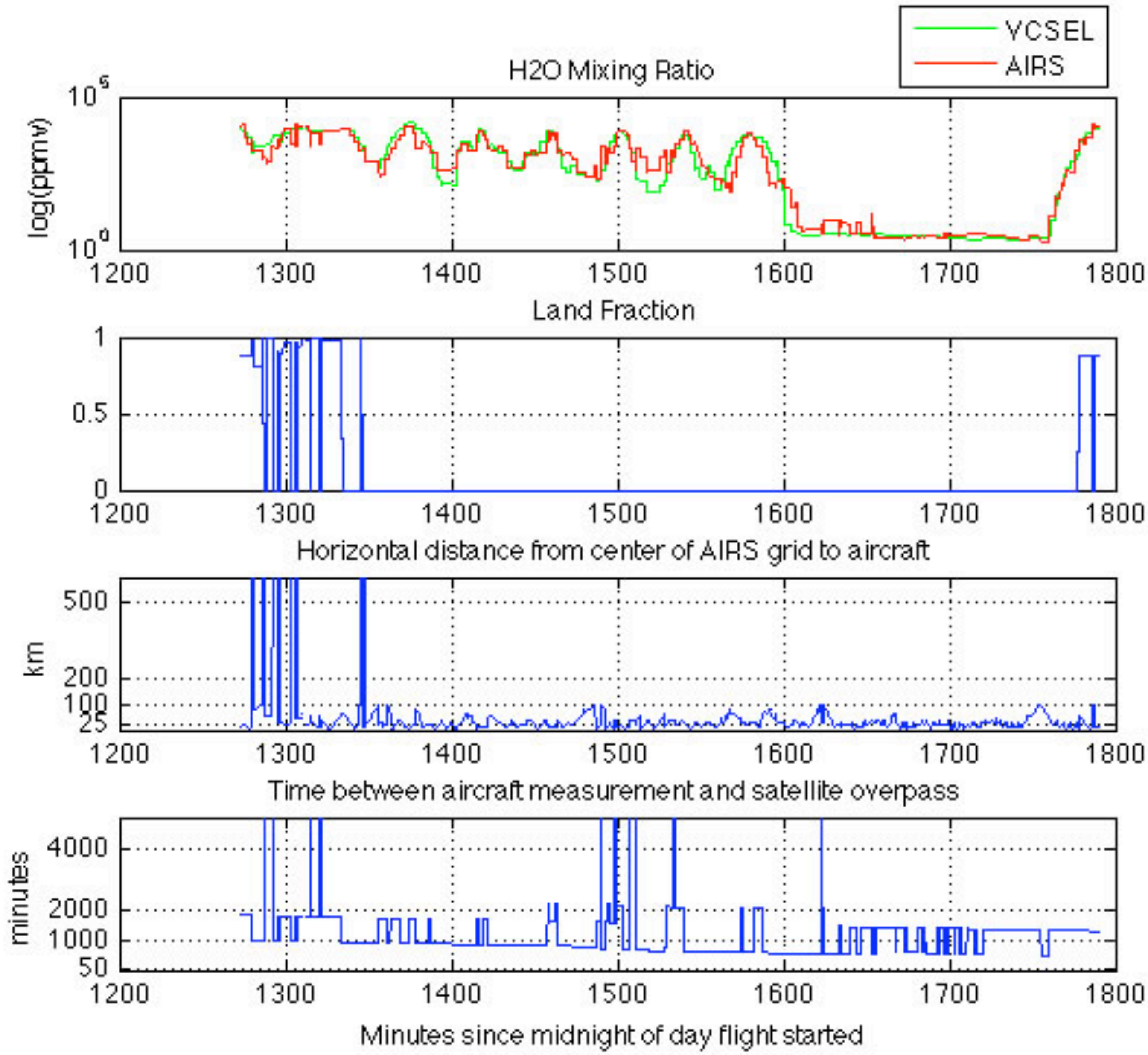
Analyzed flights 3-18 of START08 (N. America, mid-latitudes)
and meridional transect of Pacific, HIPPO Global #1(RF3-7)

….

HIPPO #1, RF07: Christchurch to 67 S and back

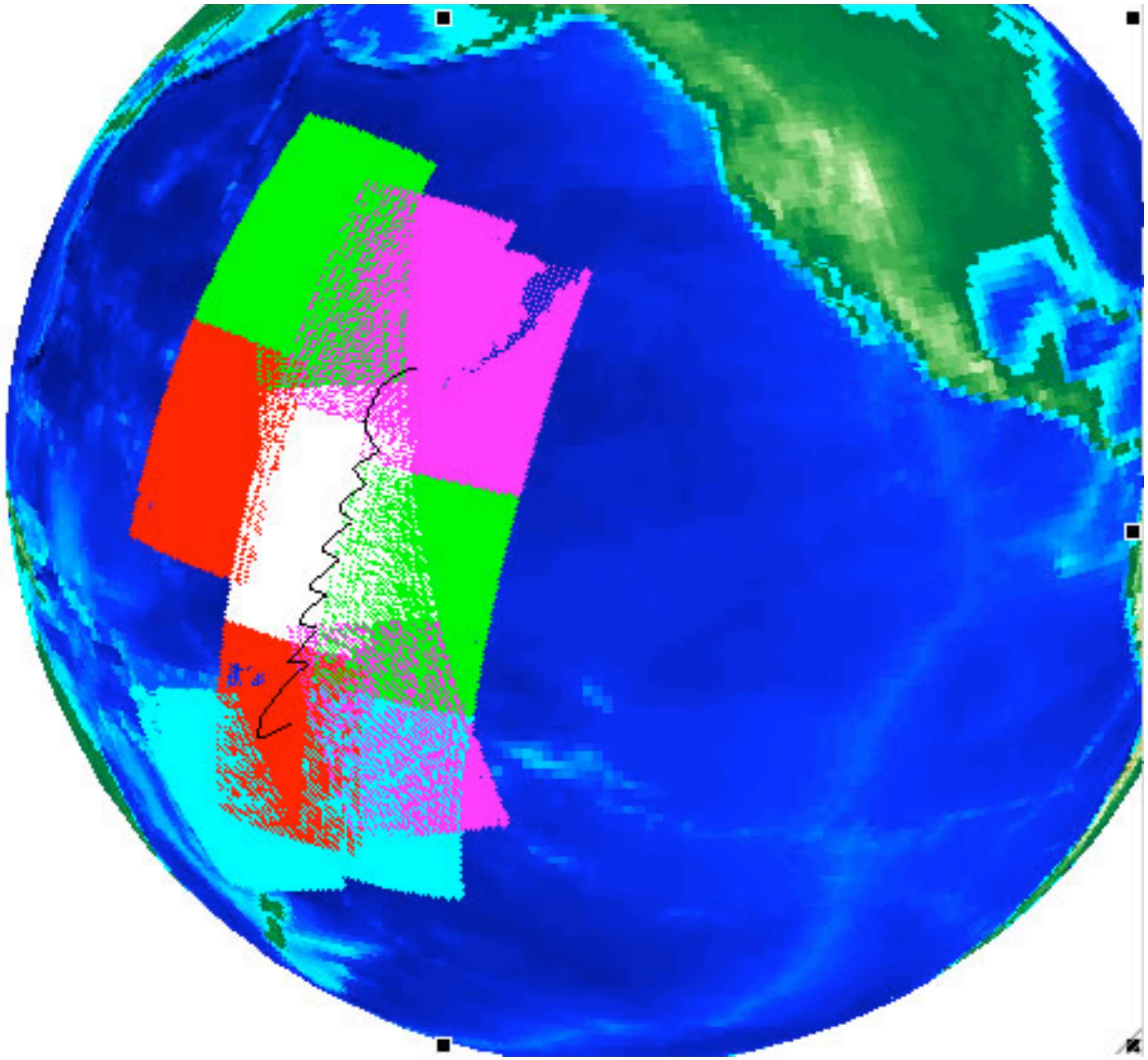


HIPPO #1, RF07: Christchurch to 67 S and back

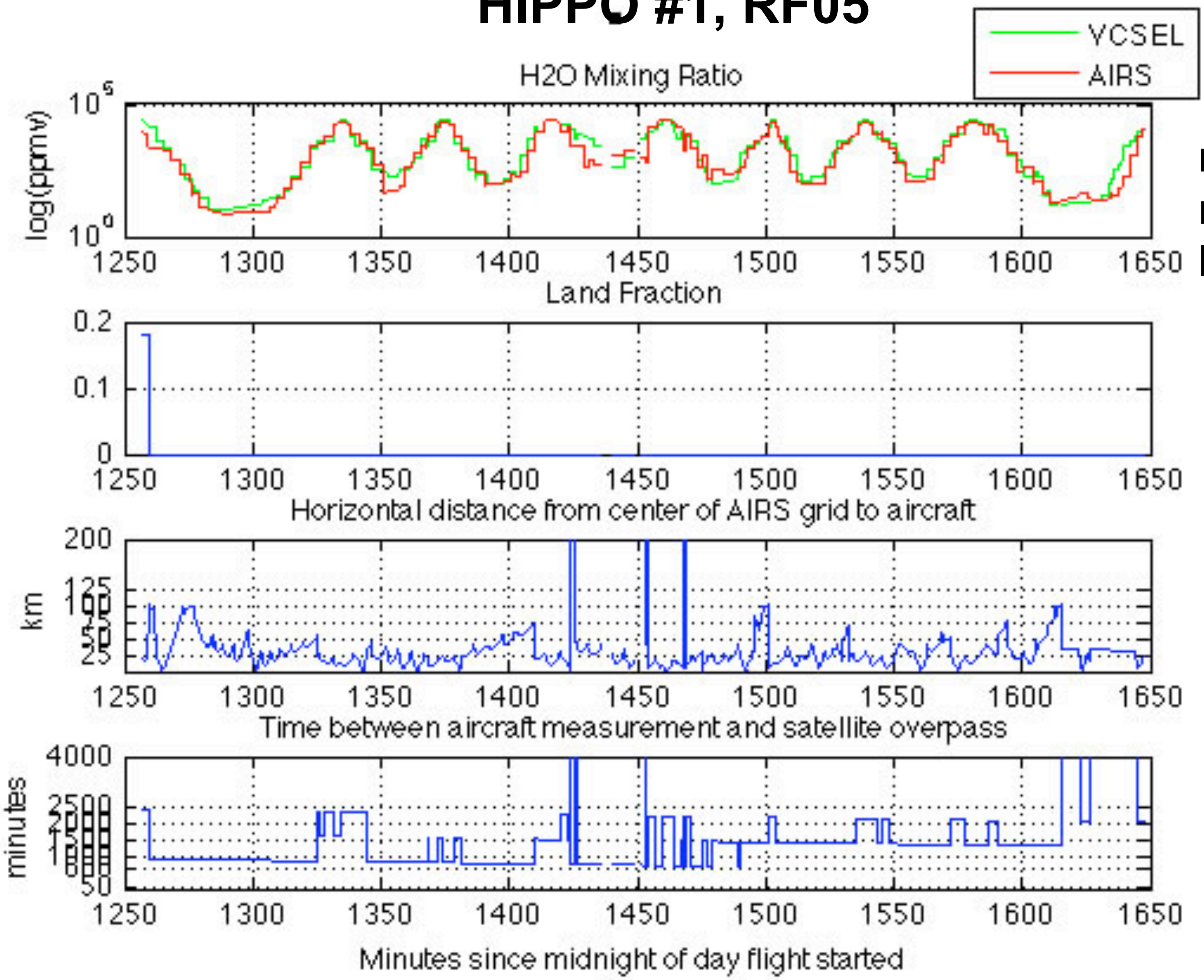


$r^2=0.92$
$m=0.86$
$b=21$ ppmv

HIPPO #1: RF05, Hawaii to Samoa

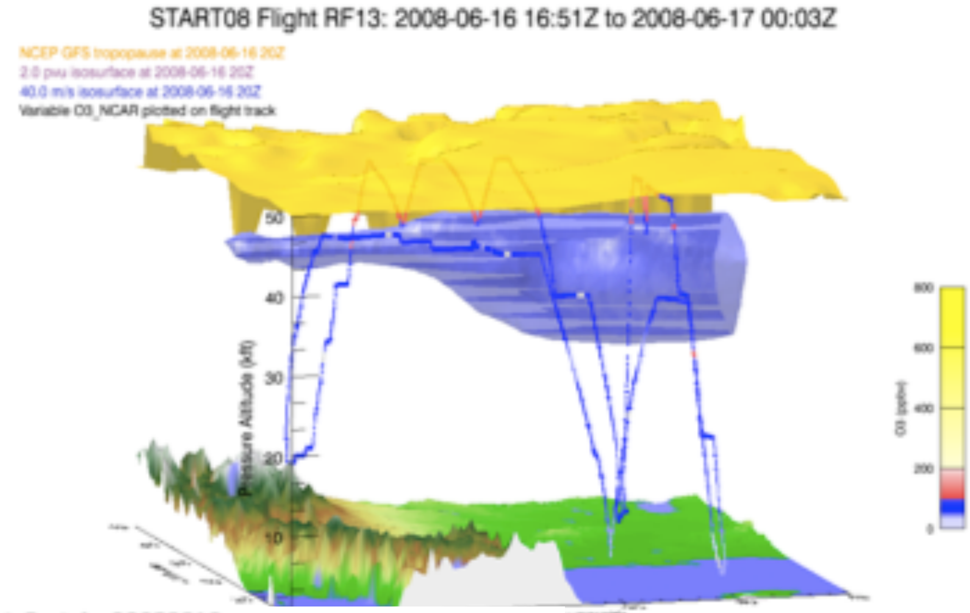


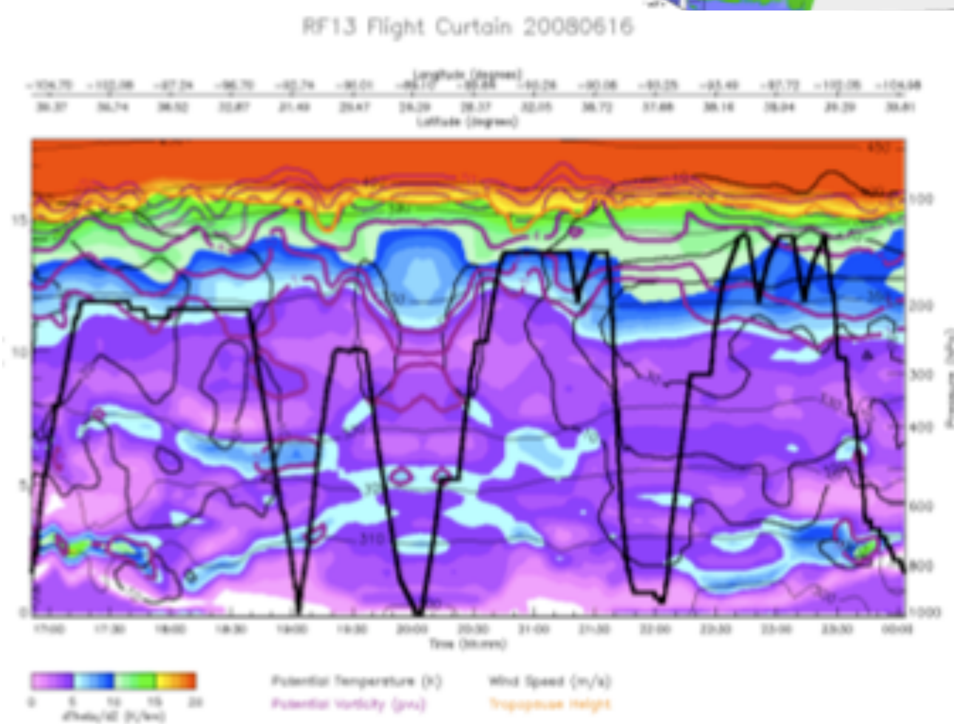
HIPPO #1, RF05



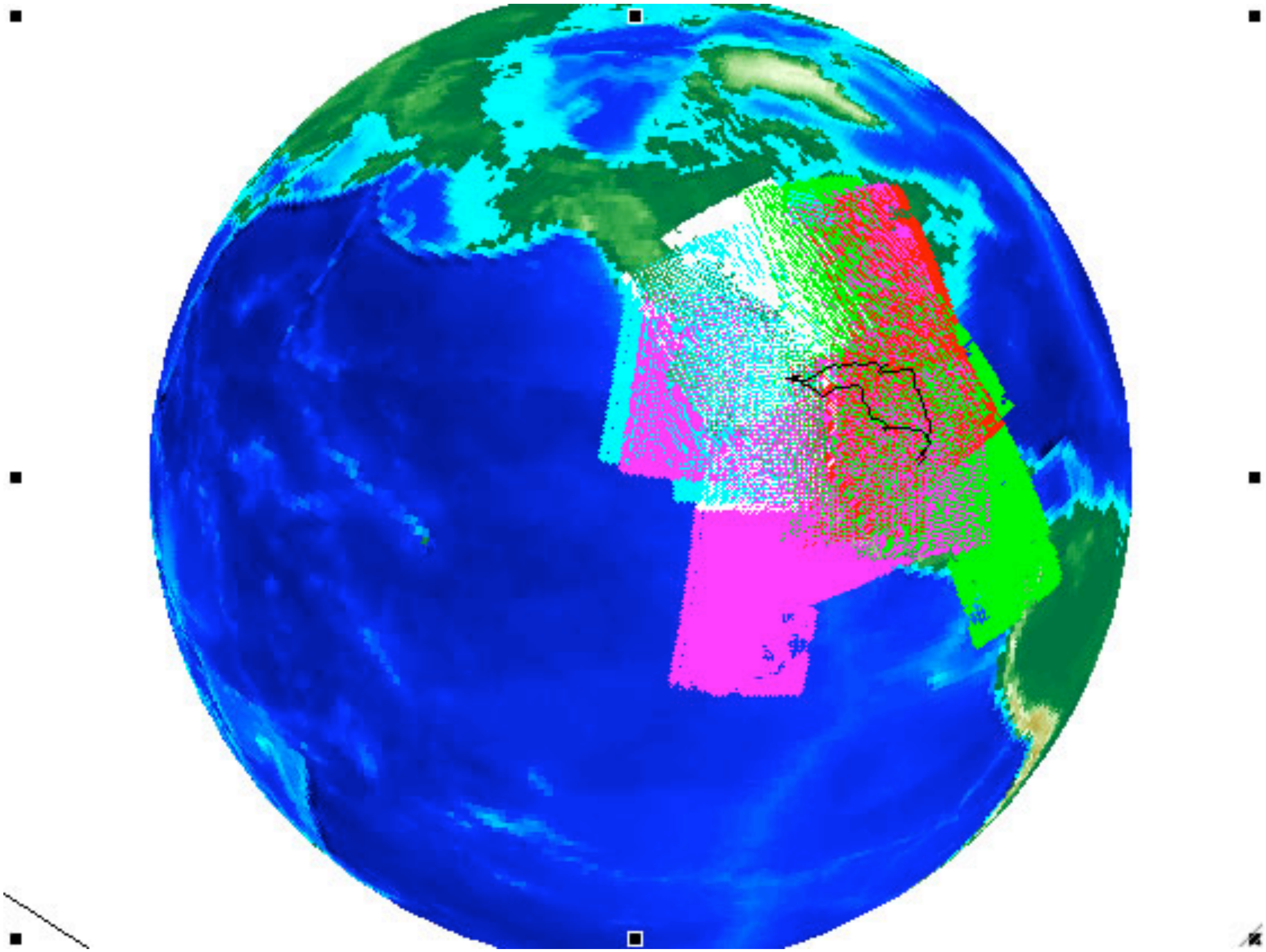
$r^2 = 0.96$
m=1.03
b=518 ppmv

START08 RF13 (troposphere)

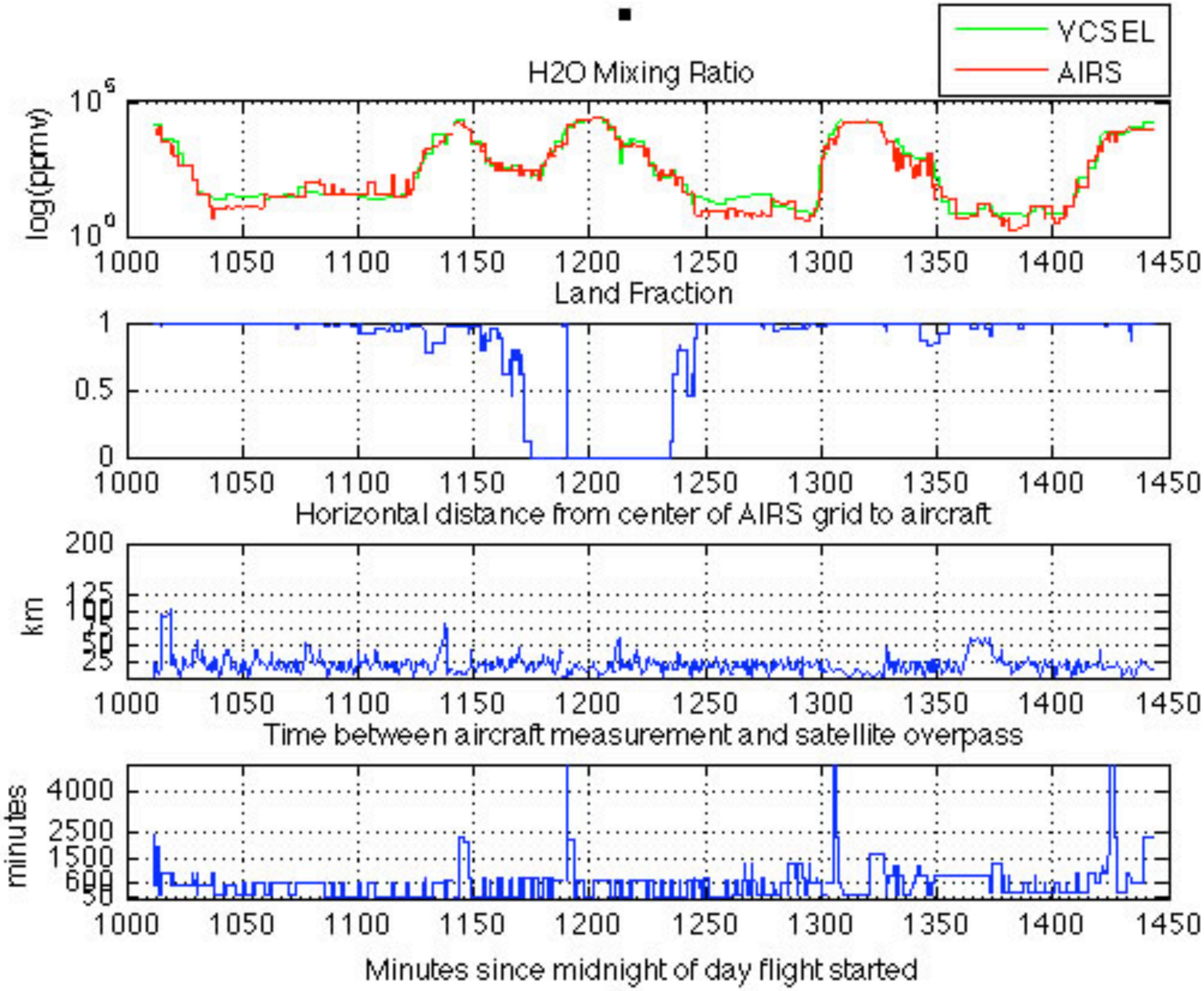




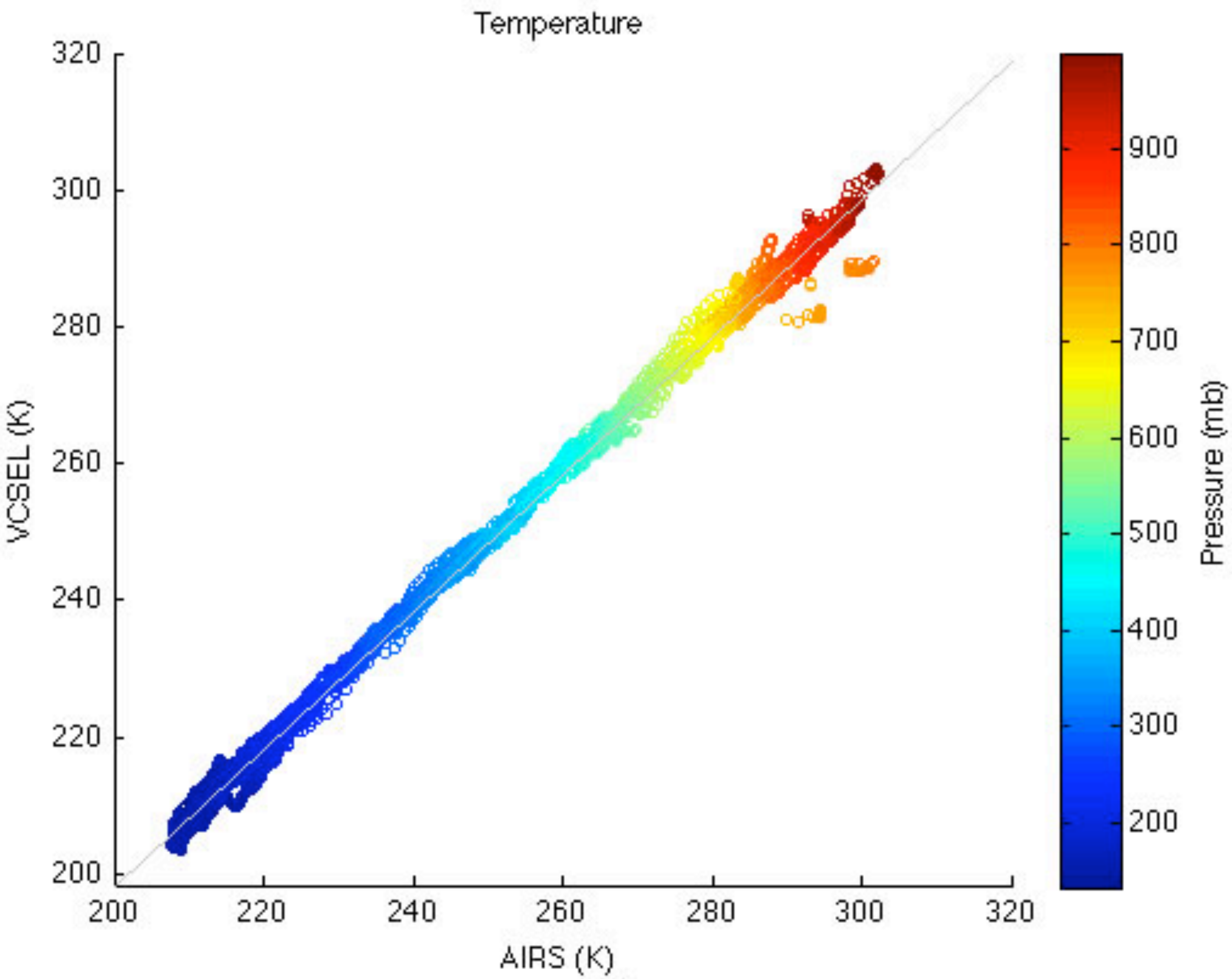
START08: Flight 13



START08: RF13



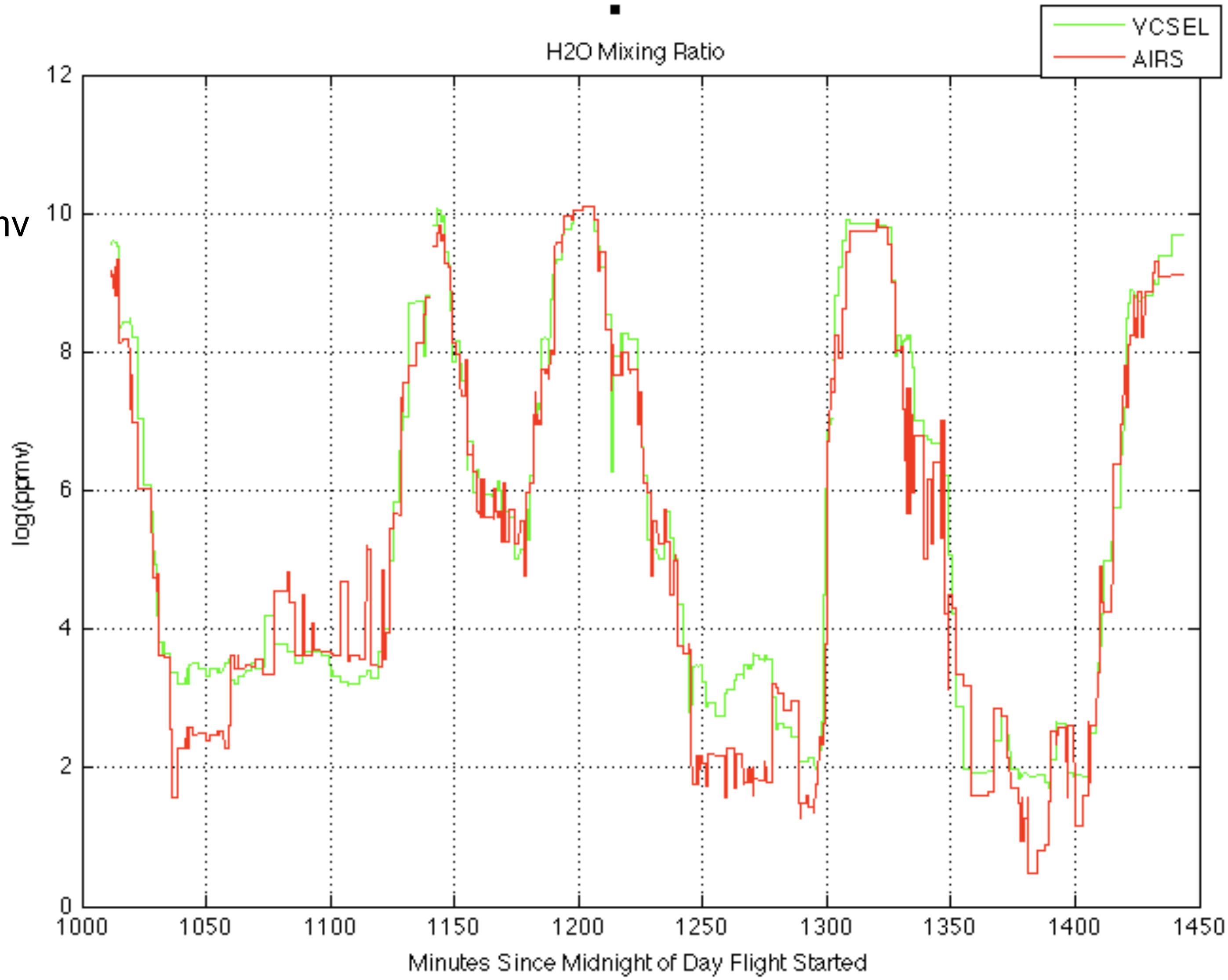
RF13: Temperature comparison



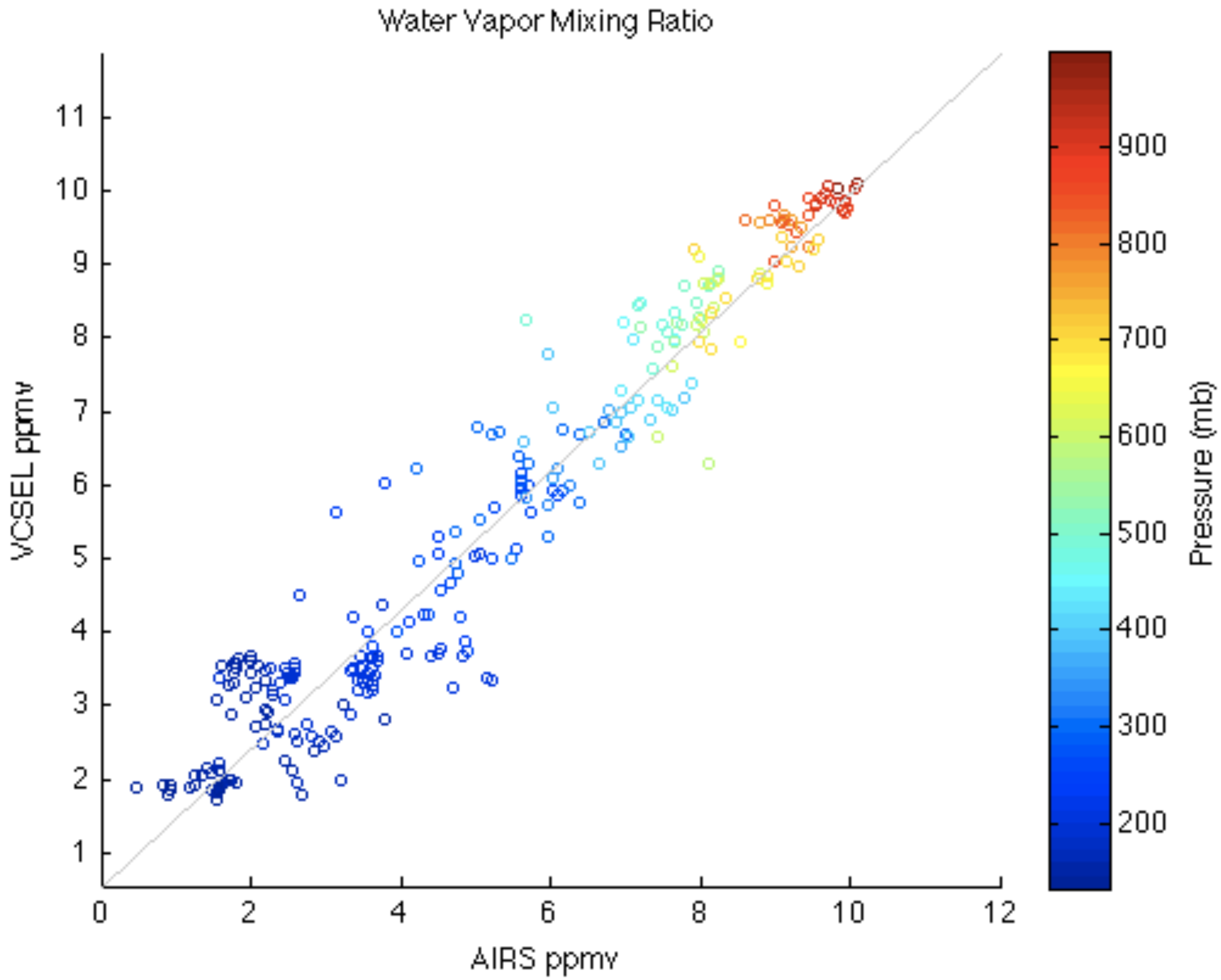
START08: RF13 timeseries

20,000 ppmv

7 ppmv



START08: RF13



r^2=0.96, m=1.05, b=467 ppmb

N=5168; Flight 82% over land; VCSEL 5% higher than AIRS

Variations in time / space

e.g. RF04 in START08 (100-150 km away from flight) (98% land)

Time (min.)	R^2	N	(Δd=100-150 km away)
0-1	0.92	32	
1-90	0.80	2600	
90-180	0.76	1640	

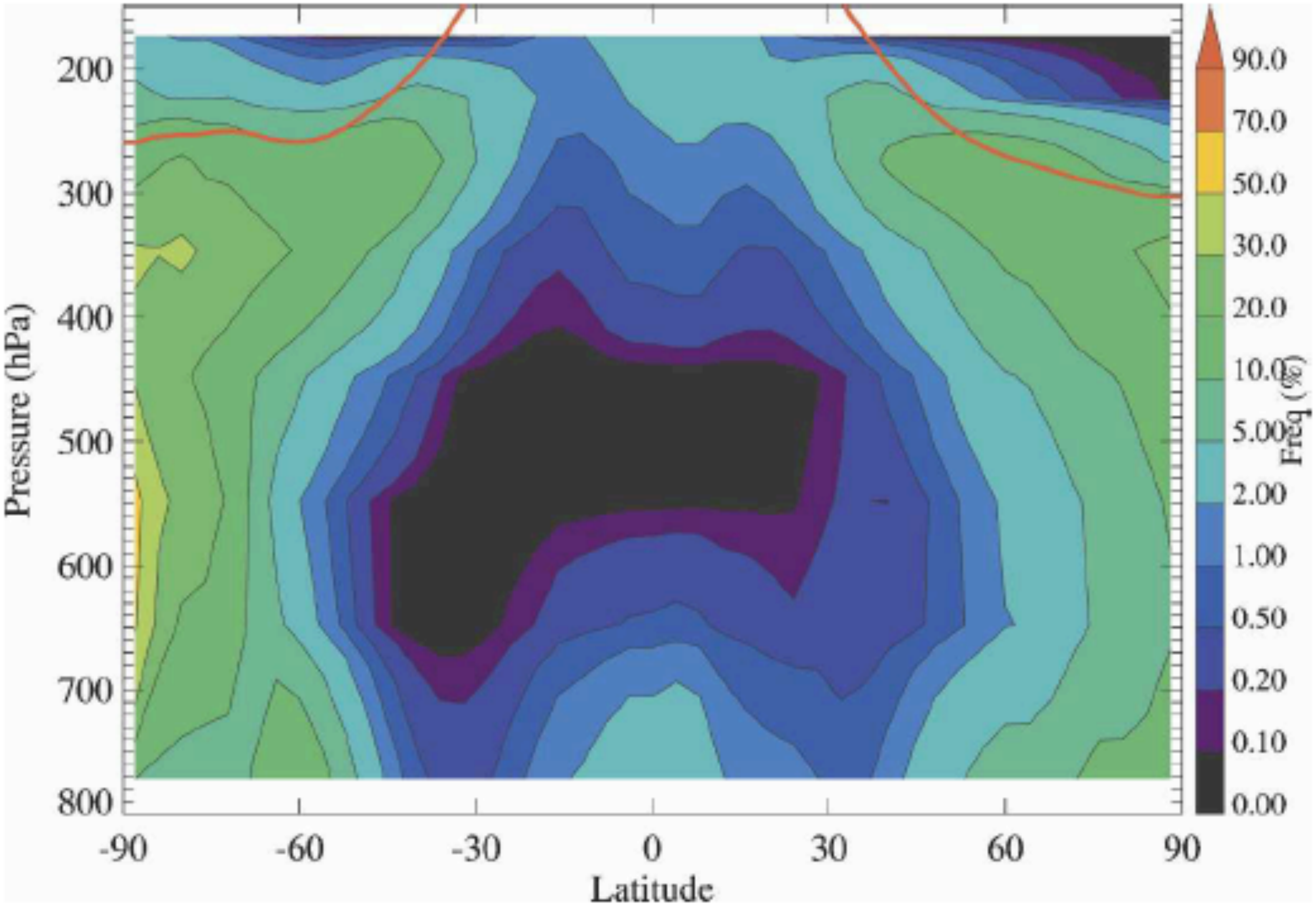
With greater ΔT, less correlation between AIRS and VCSEL

Distance (km)	R^2	N	(Δt=1-90 min.)
0-22.5	0.96	478	
100-150	0.76	1640	

With greater Δt and Δd, less correlation between AIRS and VCSEL
(need aggregate data over all flights)

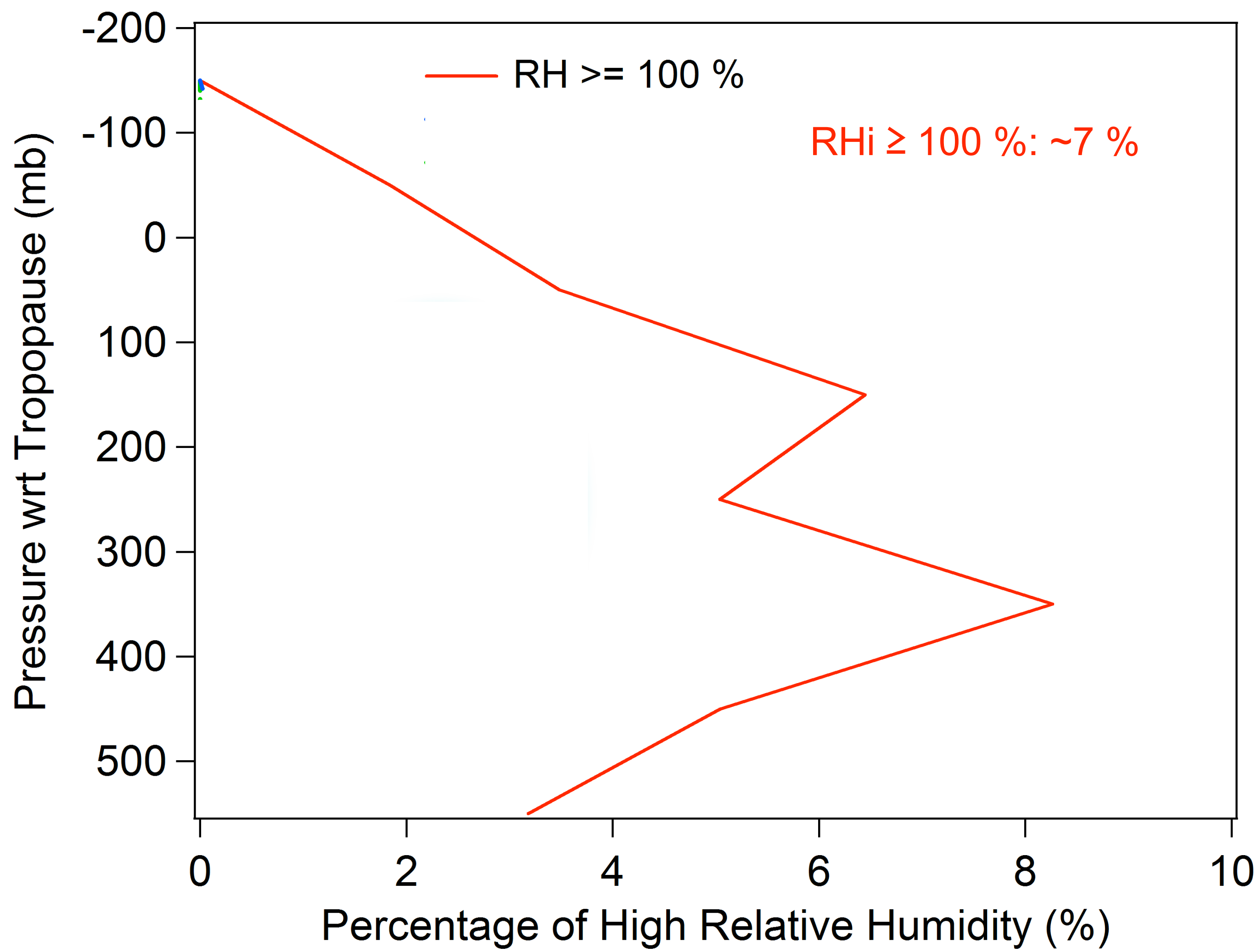
AIRS ice supersaturation climatologies

(Gettelman et al., 2006)



Large areas of ice supersaturation in polar regions

Vertical distribution of ice supersaturation

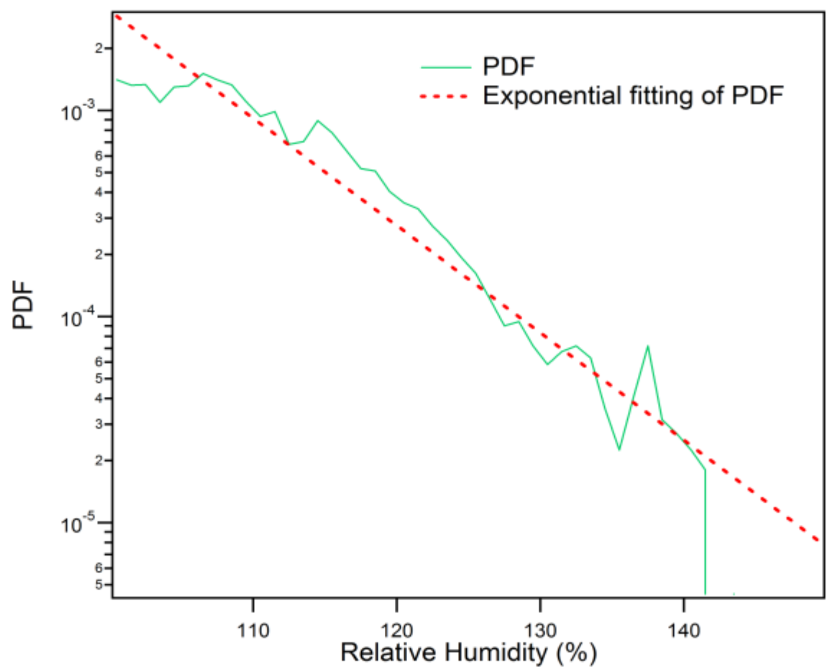


AIRS frequency of supersaturation at midlatitudes (40°–60°N) : 6.5 %

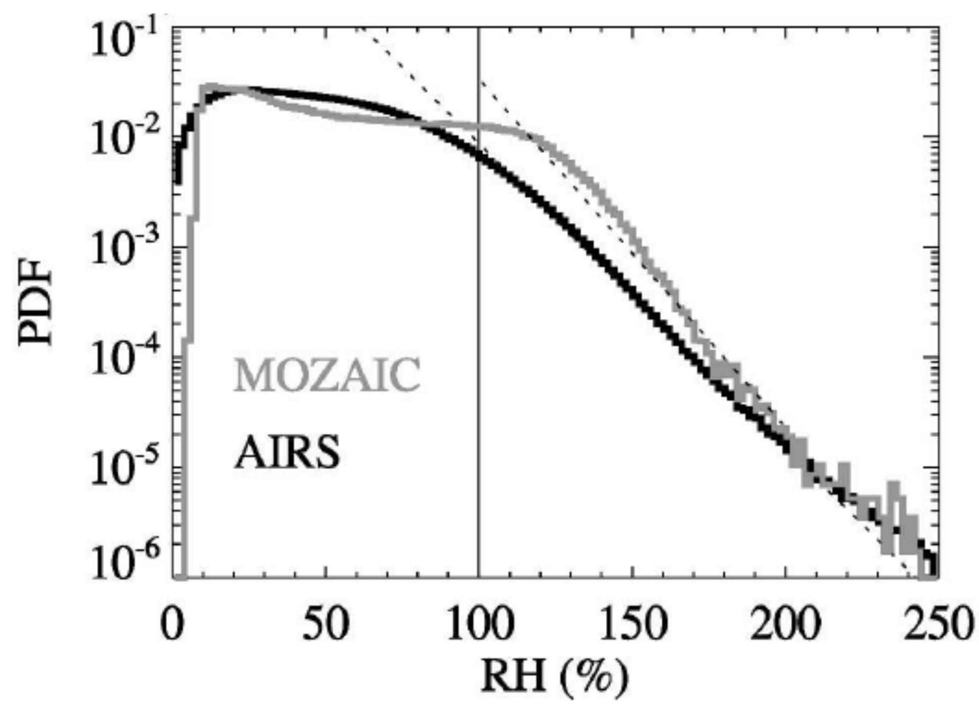
PDF of ice supersaturation

Exponential fitting:
PDF = a * exp (-b*RHi)

VCSEL (100 < RH < 150)
exponent b = - 0.12



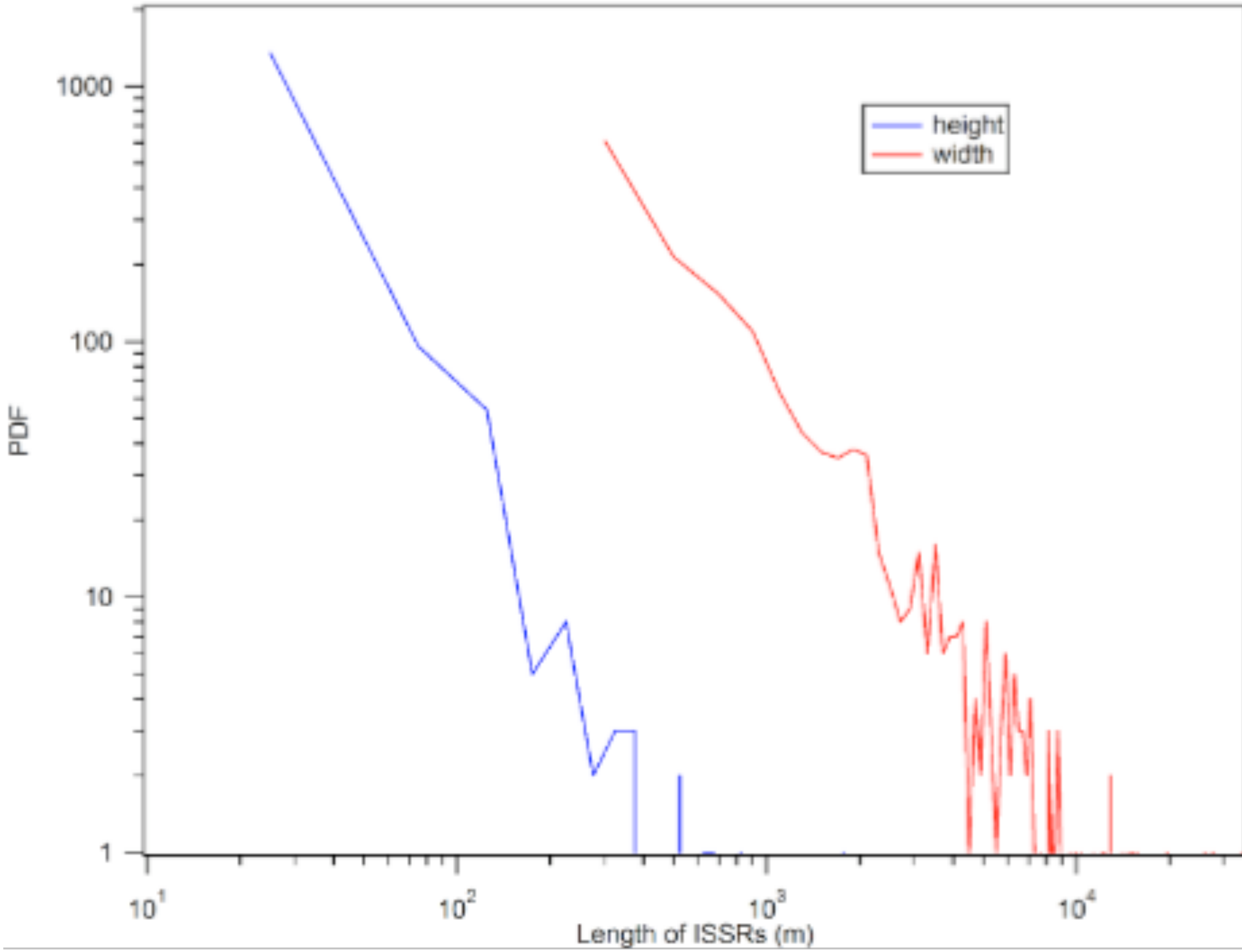
Midlatitudes 600-200mb (100 < RH < 200)
AIRS exponent b = - 0.06
MOZAIC exponent b = - 0.07



AIRS data in black,
MOZAIC data in dark gray
(Gettelman et al., 2006)

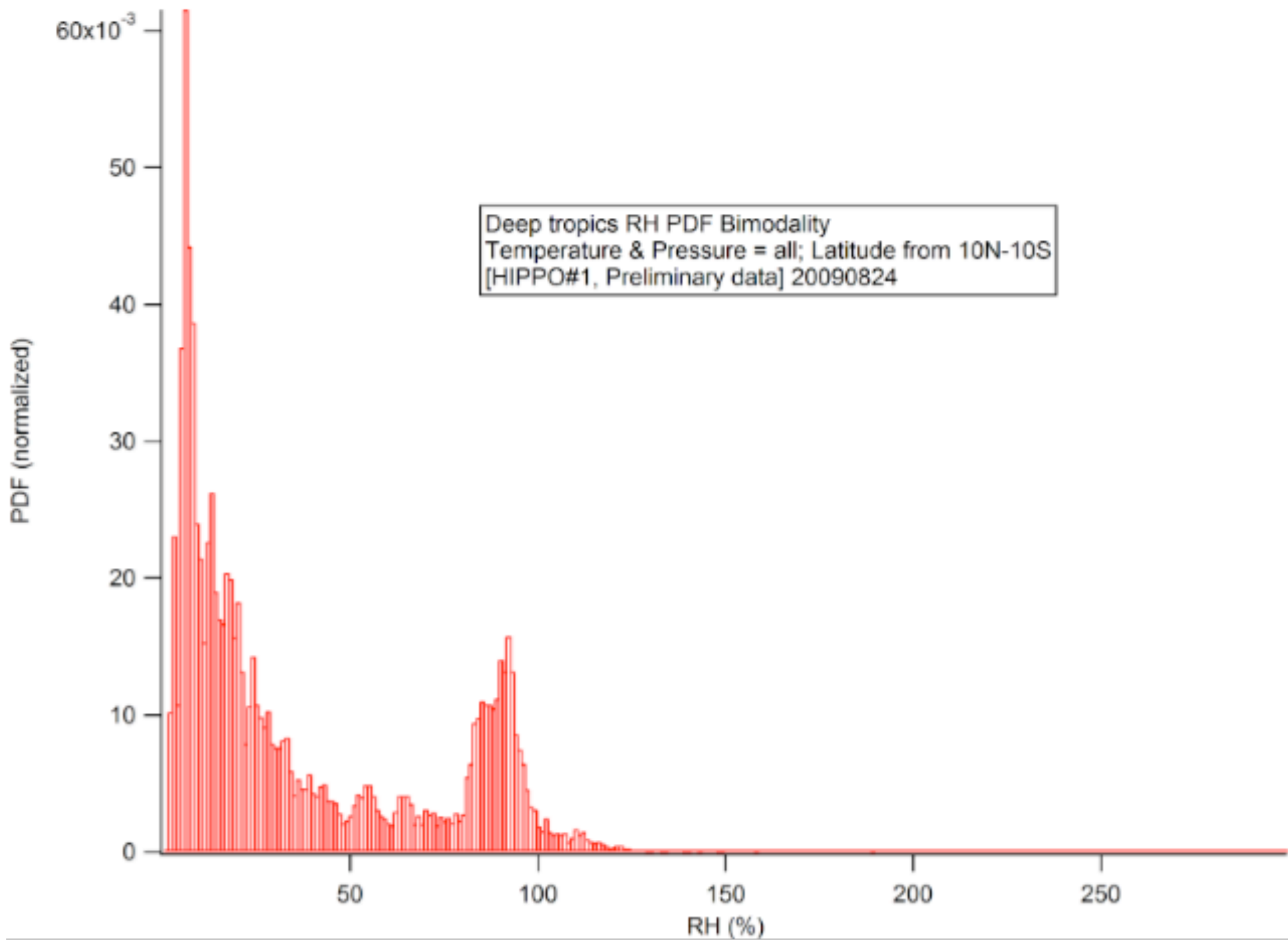
Faster removal processes seen; heterogeneous nucleation more prominent over continental North America

Vertical and horizontal scales of ice supersaturation



Most ice supersaturation regions < 100 m thick, < 1 km horizontal

RH bimodality, deep tropics, HIPPO Global



HIPPO Global will allow for detailed analyses of RH in tropical, mid-latitude, and polar regions

Summary

VCSEL instrument working well under tropospheric and stratospheric conditions:

In-flight precision <3%; 2-10% agreement with other sensors

AIRS and VCSEL correlate well over land, ocean areas

HIPPO Global and START08 datasets allow for AIRS intercomparisons in Pacific and Southern latitudes

Ice supersaturation climatologies in mid-latit., upper troposphere:

~ 7% frequency near tropopause
< homogeneous ice nucleation threshhold (~ 160%)
mid-latitude N. America in heterogeneous nucleation regime
layers < 100 m thick, < 1 km width

Future work will examine space/time correlations of aircraft/AIRS data and quantify its use for land-surface hydrology models and UT H_2O dynamics

START08 Science Team: Elliot Atlas (Miami), Steve Wofsy (Harvard), Laura Pan (NCAR), Ken Bowman (Texas A&M), Jim Elkins (NOAA), Dale Hurst (CIRES), Fred Moore (CIRES), Teresa Campos (NCAR), Linnea Avallone (Colorado), Sean Davis (Colorado), Frank Flocke (NCAR), M.J. Mahoney (JPL), Andrew Heysfield (NCAR), Bill Randel (NCAR), Brian Ridley (NCAR), Britton Stephens (NCAR), Simone Tilmes (NCAR)

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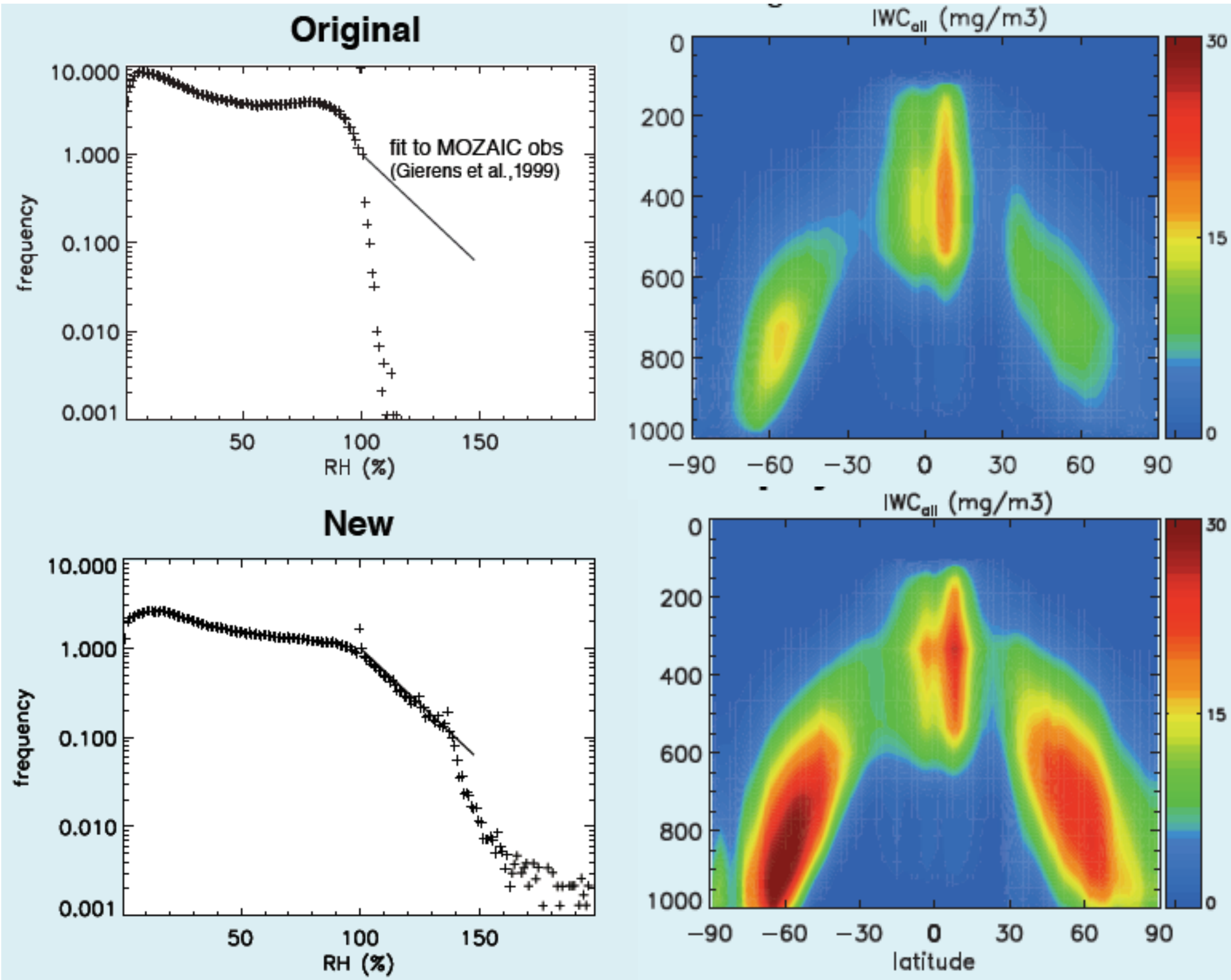
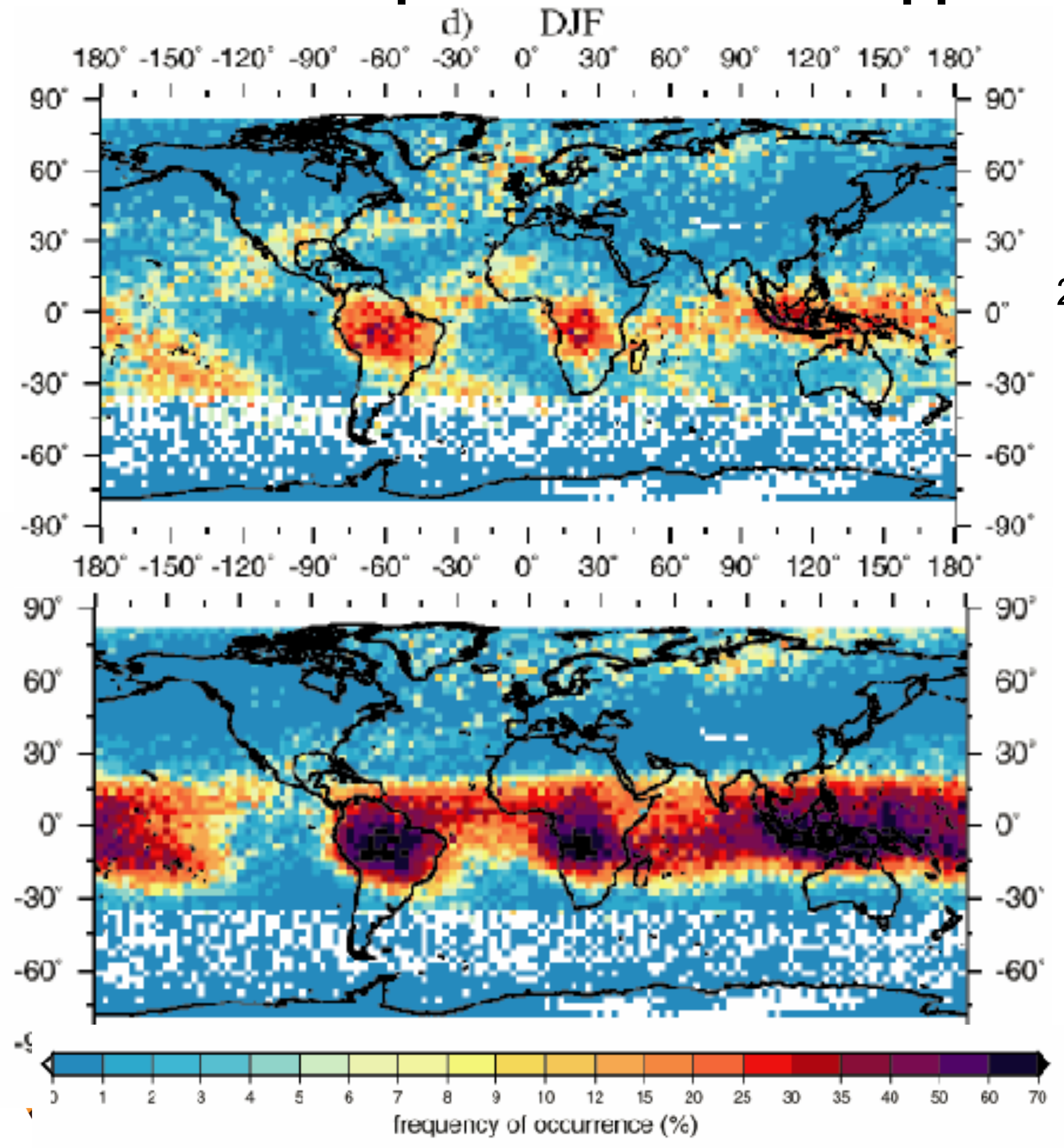
Model treatment of ISS *(Salzmann and Donner, 2009)*



Accurate ice supersaturation climatologies needed for cloud prediction

Supersaturations in upper troposphere



(Spichtinger et al., ACP, 2003)

215 hPa

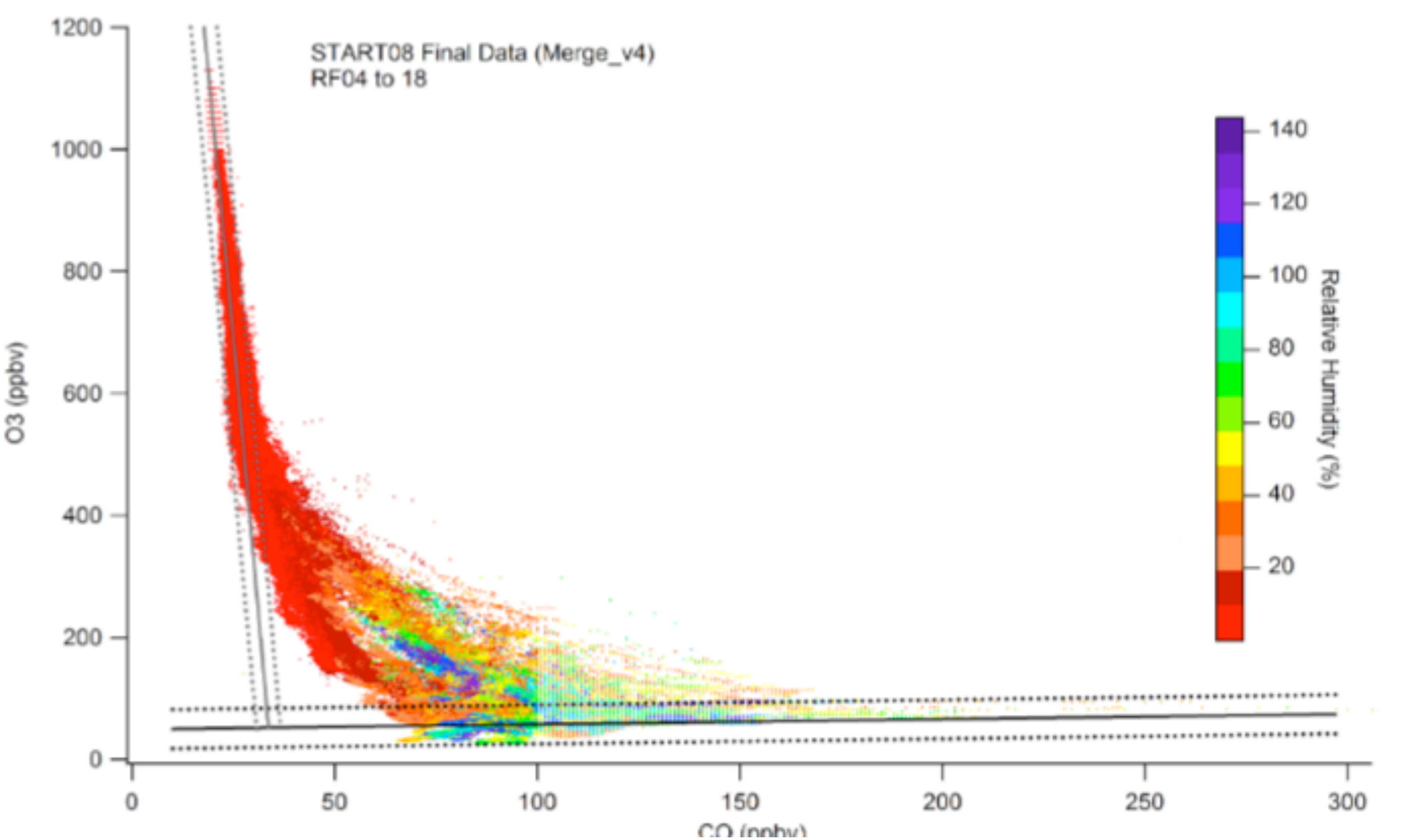
147 hPa

VET TES EN NOV TAM TVM

MIRTHE

PRINCETON UMBC TEXAS A&M JOHNS HOPKINS CCNY RICE

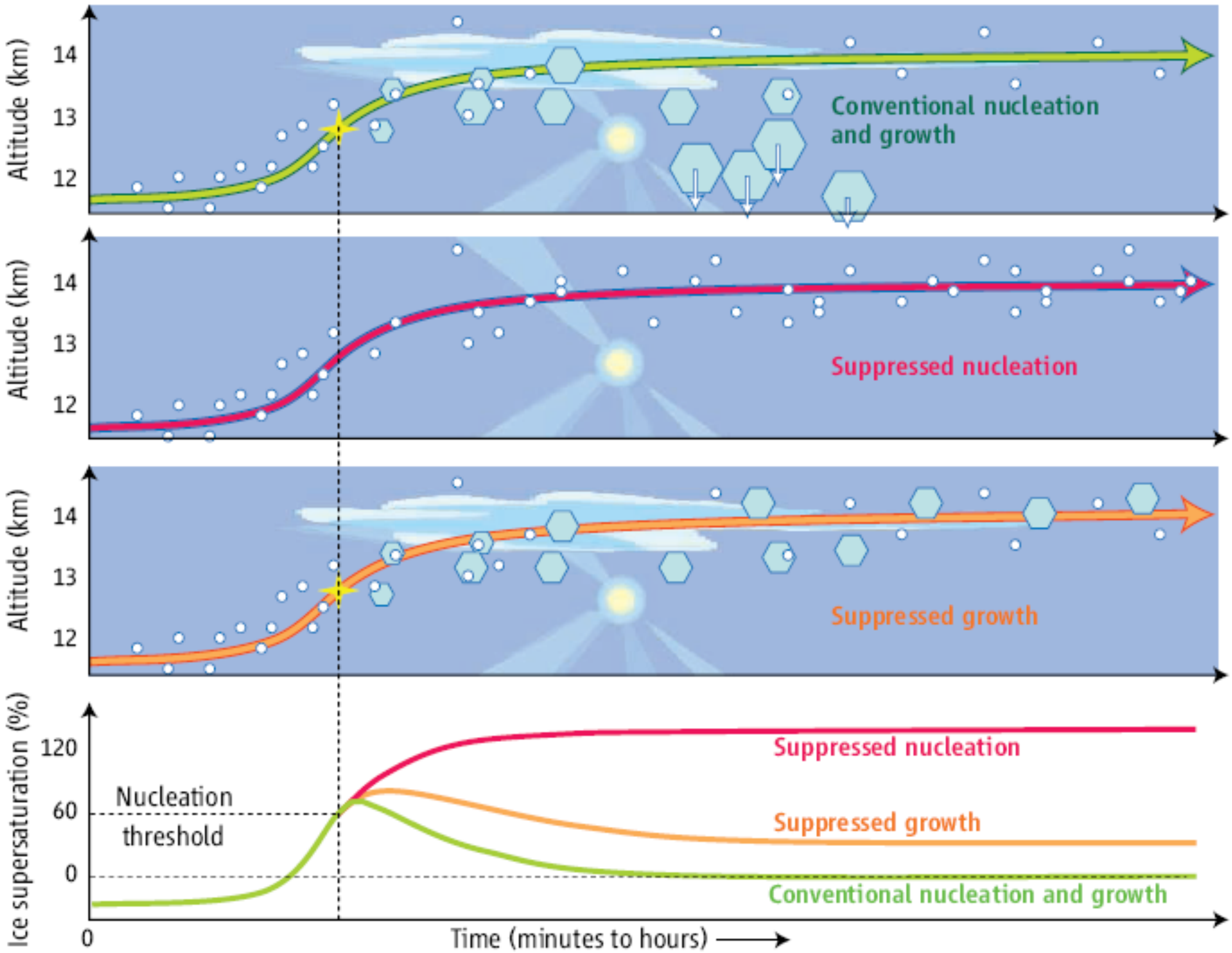
Chemical tropopause (CO < 25 ppbv; O_3 > 70 ppbv)



Most ice supersaturation occurs at or below chemical tropopause

Supressed growth or nucleation?

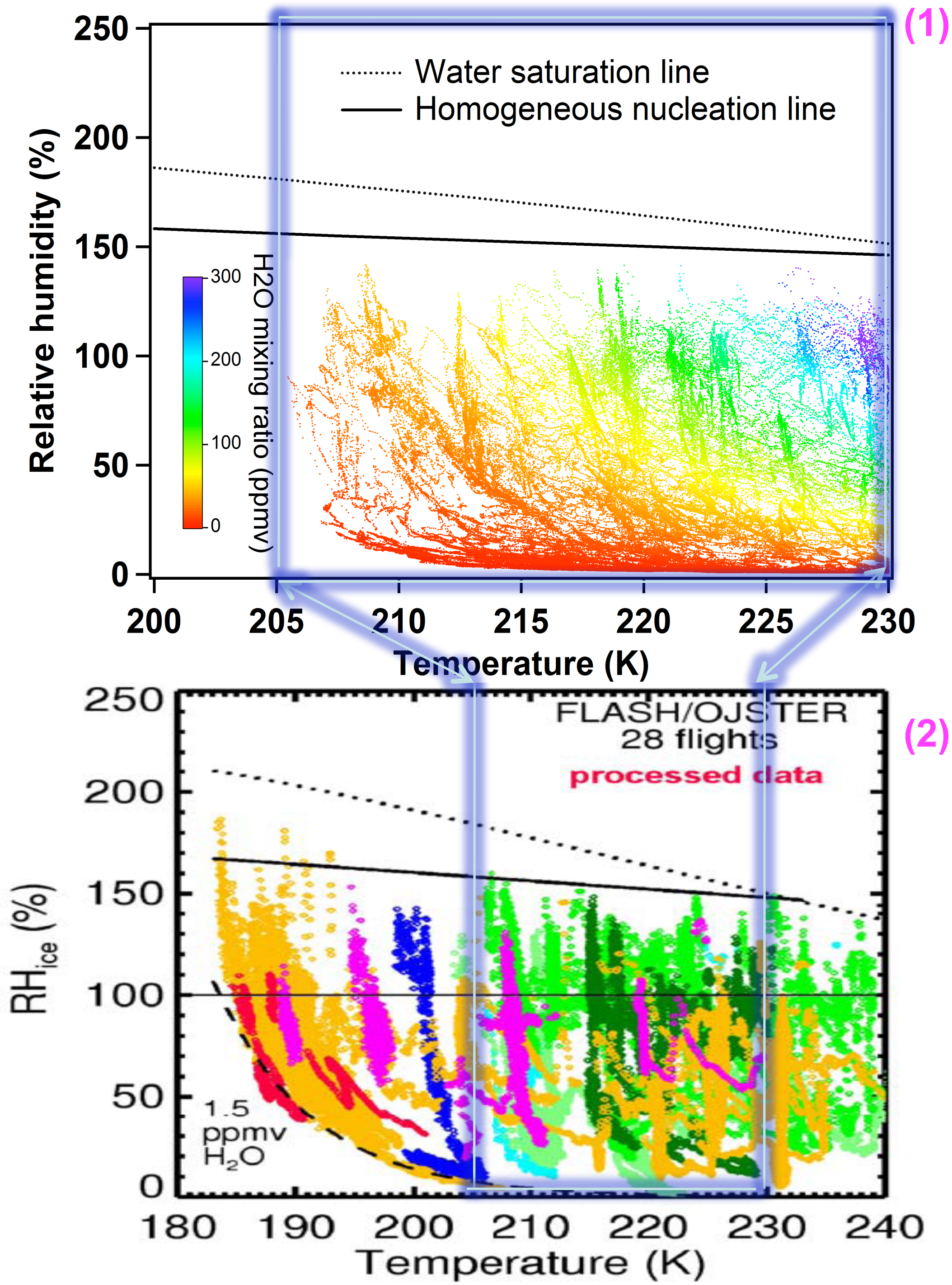
(from Peter et al., Science, 2006)



Accurate H_2O measurements critical to evaluating hypotheses

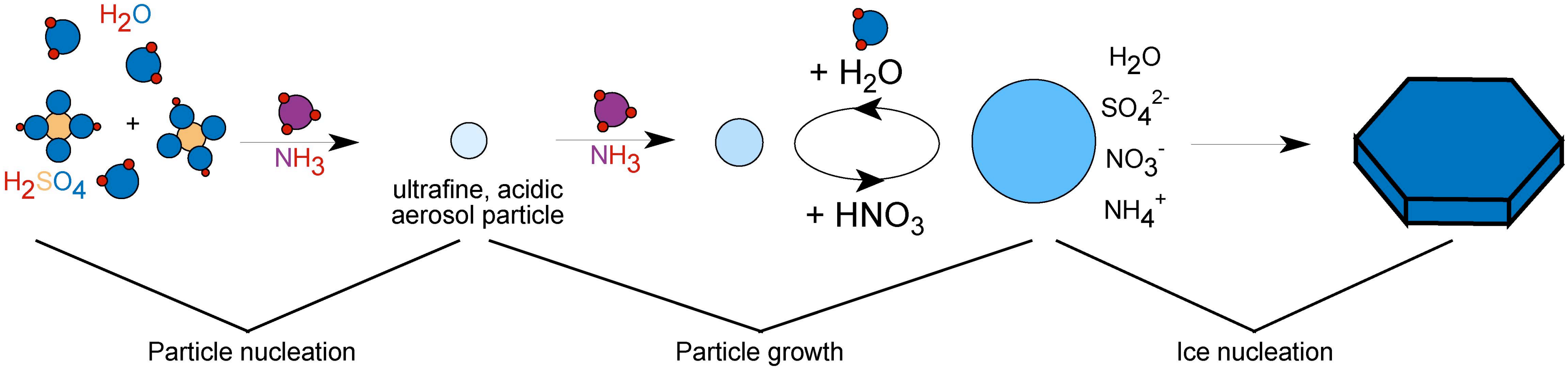
Relative Humidity vs. Temperature

1. Magnitude of RH_{ice} by VCSEL $RHice_{max} \approx 150$ %
2. Below water saturation line
3. Below homogeneous nucleation threshold
4. H_2O mixing ratio 50 – 300 ppmv



28 flight campaigns by FLASH/OJSTER
(Krämer, M. et al., 2009)

Aerosol and cloud formation

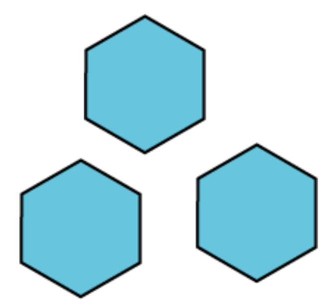


Heterogeneous ice nucleation (solid particles):

e.g. letivocite, ammonium nitrate

lower supersaturations (100-140%)

⇒ many, small ice particles



Homogeneous ice nucleation (liquid particles):

e.g. ammonium sulfate, ammonium bisulfate solns.

higher supersaturations (~ 160%)

⇒ fewer but larger ice particles

⇒ nucleation process important for cloud albedo/microphysics

Ice supersaturation (ISS)

$$\mathbf{ISS = RH_i - 1 = \ e / e_s \ - 1}$$

e: water vapor pressure (water vapor number density, air pressure)

$\mathbf{e_s}$: saturated water vapor pressure wrt ice (temperature)

e_s = exp(9.550426 − 5723.265/ T + 3.53068 ln(T) − 0.00728332*T); (for T >110K).

(Murphy and Koop, 2005)

Significance of ISS in the upper troposphere

(1) Cloud microphysics

(2) Ice nucleation mechanisms

(3) Atmospheric radiative forcing

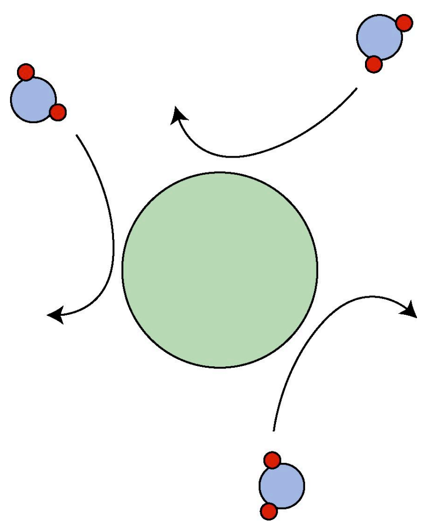
RH(ice)=120% same as supersaturation=20%

Ice supersaturations outside clouds

Examining ice supersaturation climatologies:

how widespread are these areas?
what is the frequency and depth of these areas?
what scales do they exist in vertical and horizontal?

Potential explanations:



1. Nucleation resistant aerosol particles
   (DeMott et al., PNAS, 2003)

2. Organic films reduce H_2O accommodation
   (Cziczo et al., JGR, 2004)

3. Ice vapor pressures too low
   (Murphy and Koop, Q.J.R. Met. Soc., 2005)

4. Amorphous organic glass formation
   (Murray et al., APC, 2009)

What is the climatology of ice supersaturated regions?